AUGUST 1951

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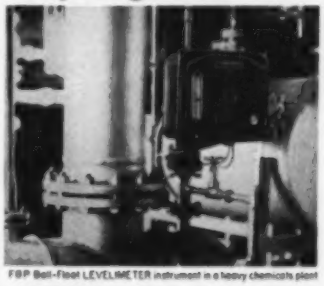

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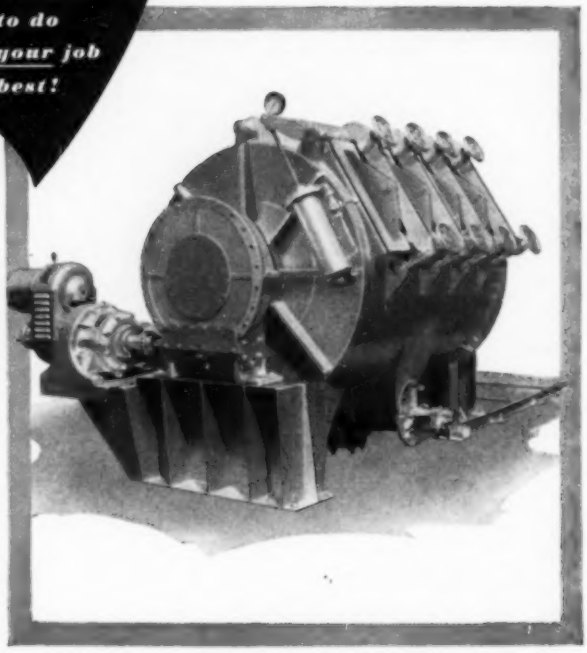

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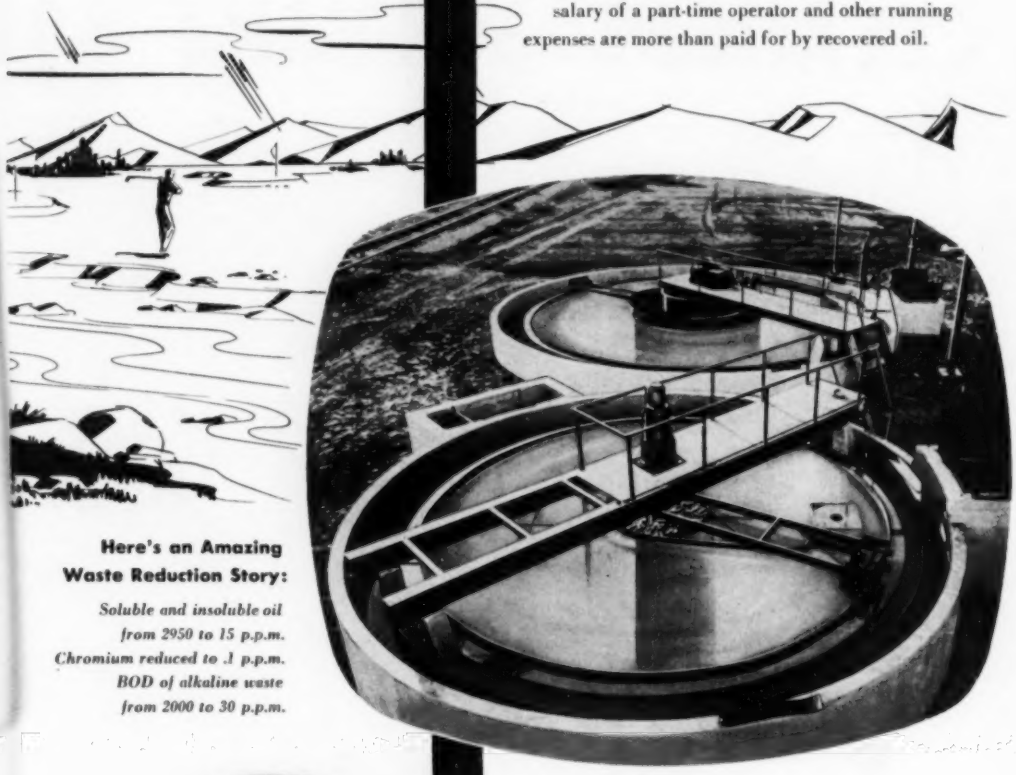

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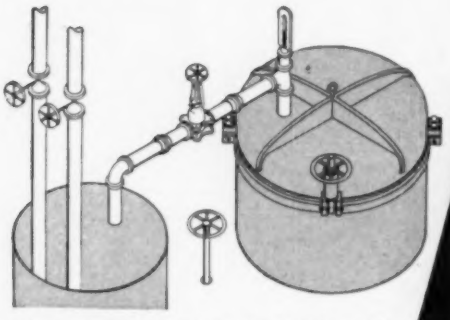

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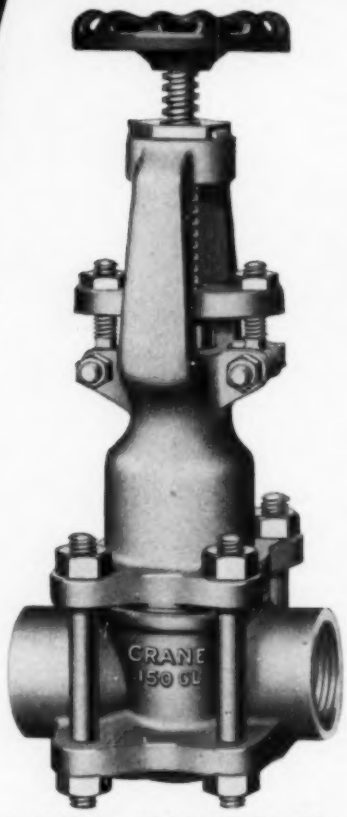

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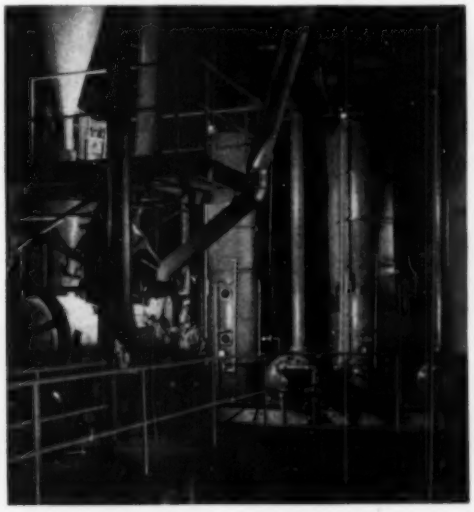

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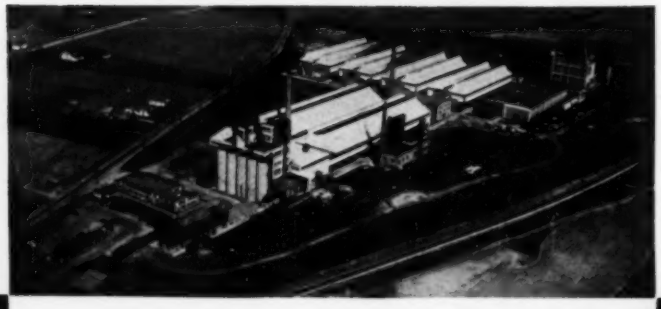

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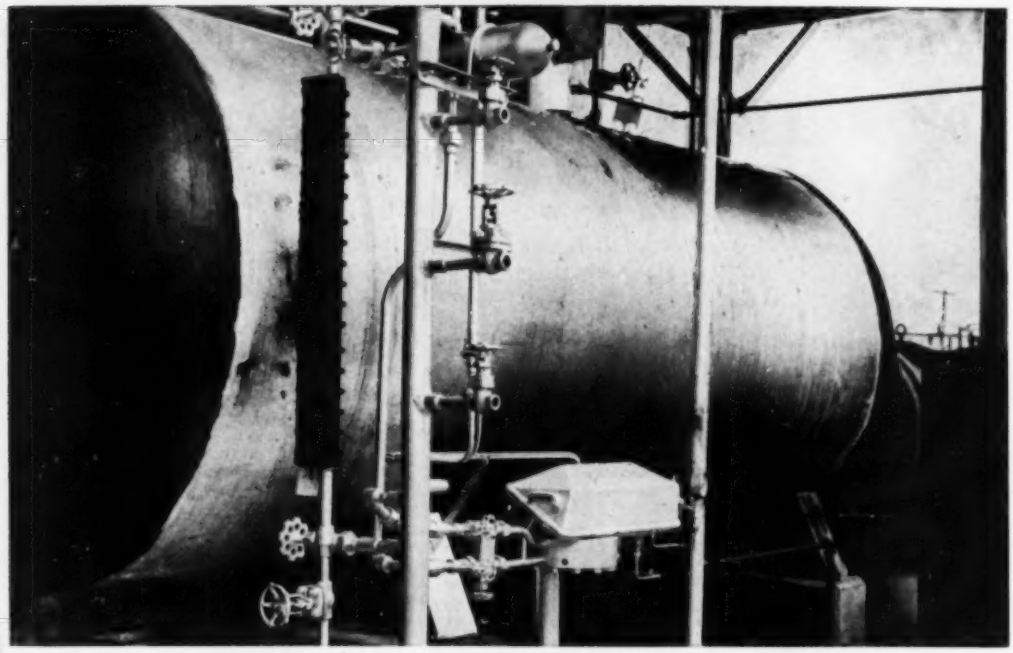

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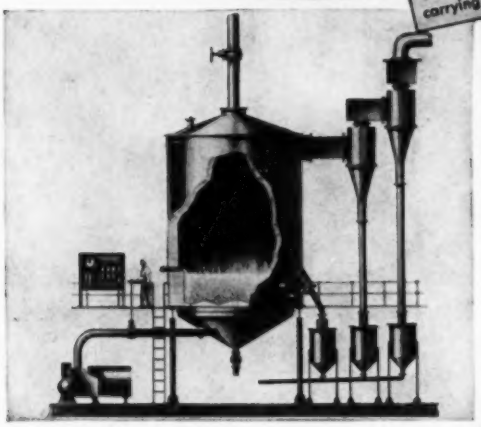

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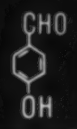

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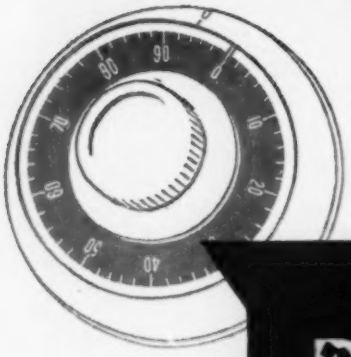

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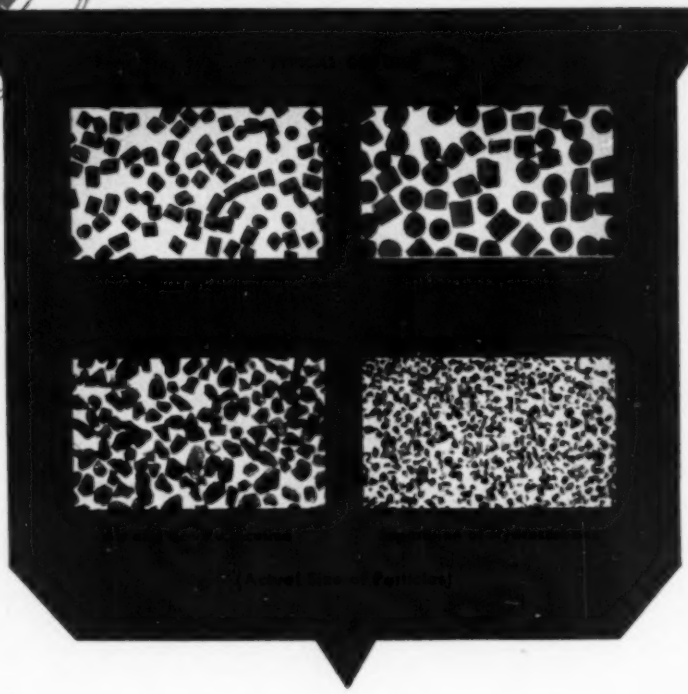

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OPINION COMMENT

MATURITY AND RESPONSIBILITY

WHEN baby brother succeeds in pulling the knob off the radio and abandons it for something more interesting, little sister reports to mother that it needs fixing. Father, with only a little prodding by mother, puts aside whatever is absorbing him to get the screwdriver and make the repair, and mother rolls out the carpet sweeper to clean up the mess that father left. Responsibilities were accepted as each individual recognized them.

In general, one sees most clearly his responsibilities toward the persons and affairs closest to his daily life. The broader the education and outlook, the wider are the responsibilities he recognizes. The narrower the intellectual outlook and the more confining the specialization, the more restricted are the responsibilties he accepts. In a complex civilization where increasing specialization is a technical requirement and narrow group identification is a consequence, the shrinking sphere of individual responsibility is a growing danger. The doctor who treats his patient for a lung ailment feels that his responsibility for the patient's liver condition is completely discharged by referring the patient to another specialist. But the general practitioner still feels that he is responsible for the whole man. On the other hand, the city voter, who looks upon his municipal government as remote and impersonal, shrugs off bad management by saying, "I can't do anything about the political machine," while the village citizen exhorts his neighbors and takes his complaints directly to his councilman.

The authoritarians, Marxist and others, tell us the end result is inevitable, that man must behave like the ant; that in order to preserve the materialistic benefits of a complex society, man must forego his individuality by shifting his responsibilities to the state, which will take care of all his material needs through the superior wisdom of the bureaucrats. He is promised that he will like it too, that he will be relieved of the burden of making decisions and be spared the difficulties of ethical choices. To make his happiness complete he needs only to abandon his maturity and accept childlike dependence.

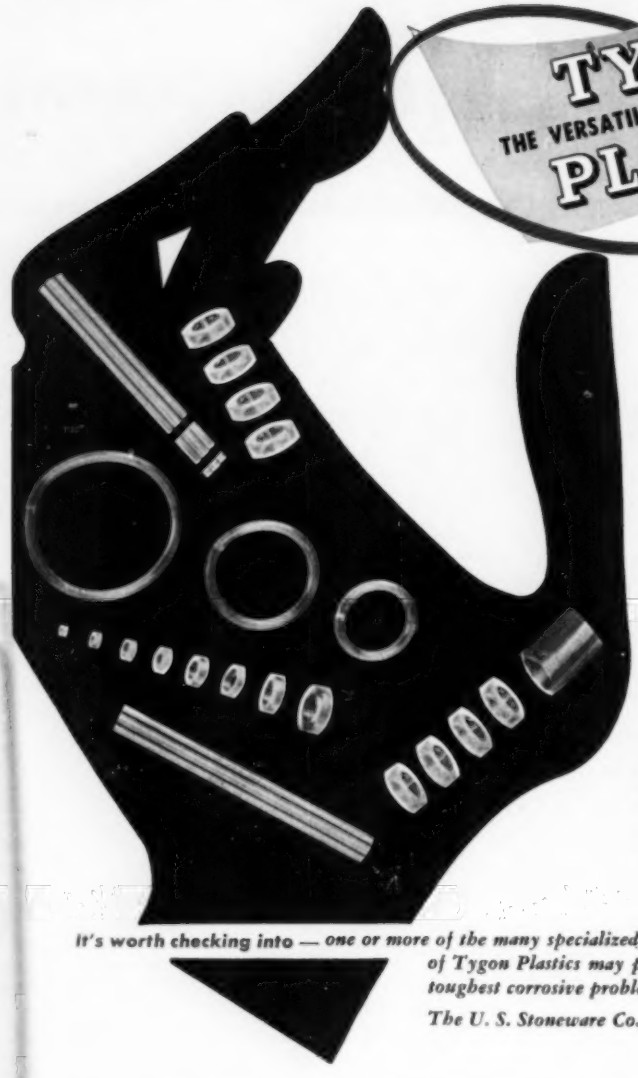
With such a Utopia vigorously propagandized and militantly exploited, why has only a small minority of men voluntarily accepted it? Perhaps it is that "man does not live by bread alone," that in spite of the burdens that manhood implies, men don't want to be children, that an essential need of man's nature is to strive for maturity. The phychologists may be stating an elemental truth when they say that a man's psychic income, his happiness, is at a maximum when he is able to fulfill the responsibilities that he recognizes as his own.

H. A. Overstreet, in his book "The Mature Mind," says that the mark of a mature mind is the recognition of responsibility for the needs of others. Mature responsibility, however, implies more than this. It requires weighing the needs relative to each other and to the means available, and above all, it avoids promising more than can be delivered. Engineers, and especially chemical engineers, exercise a high order of such mature responsibility in their daily work. In fact, the engineer's judiciousness is often the despair of welfare enthusiasts to whom some need is so imperative as to rule out all considerations of other needs which compete for the taxpayer's dollar. For instance, when Congress was considering a proposal to spend 778 million dollars to irrigate 100,000 acres of desert land, an engineer raised the objection that this expenditure of nearly $8000 per acre was many times the market price of the most valuable agricultural land in the country. The engineer was roundly denounced for his "unsocial attitude" in "putting money above human needs" by a public official to whom, obviously, desert reclamation is more important than public health, or education, or even national defense.

For the ultimate preservation of the kind of society in which men can grow to maturity, it is as essential for leaders to be hardheaded in discharging their responsibilities as to be softhearted in recognizing them. As long as engineers continue to insist that the return must be commensurate with the cost, whether in private industry or public affairs, they are fulfilling the primary social responsibility for which society has trained them. If in addition to being hardheaded economically, some of them have the superior drive and ability to work in a wider social field, both they and society will gain.

In the final analysis, however, the responsibilities each of us accepts are strictly his own. As Channing said, "Every human being has a work to carry on within, duties to perform abroad, influences to exert, which are peculiarly his and which no conscience but his own can teach."

Mott Souders, Jr.



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CHEMICAL PLANT CONSTRUCTION COST

Indoors versus Outdoors

J. R. MINEVITCH, G. B. KNIGHT, S. E. ROOT, and H. E. BORAKS

E. B. Badger & Sons Company, Boston, Massachusetts

This article concludes the series on indoor versus outdoor construction of chemical plants which began in the June issue . . . three of the four papers pointed up the merits of the outdoor-type installation and concluded that the outdoor plant offers advantages over the completely housed type . . . this final paper deals with the savings that can be anticipated by the elimination of expensive enclosures usually employed in the indoor-type plant. . . .

IN discussing the factors which affect the comparative investment costs of indoor and outdoor chemical plants, and the differential between costs of plants of each type, it is felt that although the exact decrease in investment accruing from outdoor design cannot be fixed for all types of plants, the average cost differential found in the cases investigated will be helpful in weighing the merits of open construction for a particular process.

In setting up a basis for comparison of indoor and outdoor installations, it is well to define some features of each type. In this paper a typical outdoor plant is one in which the process equipment is supported at grade, or in structures, without enclosing walls or roof; but one in which the operating control station is fully housed in a heated building which may be air-conditioned or pressurized if climatic conditions or safety considerations warrant. Where pumps are grouped on the ground level, they are usually roofed-over, but not walled-in. Indoor plant design, as the name implies, requires all processing equipment and accessories to be inside a building. Only bulk storage facilities are unhoused.

The severity and duration of winter weather and the amount of precipitation to be expected are important considerations in plant design. Plants considered in this paper are designed for locations subject to normal amounts of rain and snow, and at least three months of winter weather during which subfreezing temperatures are expected and temperatures down to —20° F. may be experienced. This would correspond to weather conditions in New England, the Middle Atlantic States, and much of the Middle West. For these assumed conditions several types of building materials are acceptable. However, the comparisons presented here are limited to the use of structural steel to support equipment, and the use of red common brick and steel for building construction. This construction is in common use today for indoor plants in regions where severe winter weather is encountered.

Under such conditions there are two requirements for successful outdoor plant operation:

1. The process must allow instruments, controls, and facilities requiring regular attention, to be grouped in a control-house which is enclosed for the protection of operating personnel.
2. Without itself requiring shelter, equipment must protect the materials being processed from harmful effects of weathering.

The advanced development of remote indicating, recording and controlling instruments, together with the protection to materials afforded by pipe lines, makes processes handling fluids inherently adaptable to outdoor design. On the other hand, plants handling solids liable to damage by leakage of atmospheric moisture, dust and other contaminants are less adaptable.

Some advantages and disadvantages of outdoor and indoor design may be reviewed:

1. *Plant Investment.* The outdoor plant will cost less to build than the corresponding indoor facility.
2. *Maintenance and Repairs.* The outdoor plant will sometimes cost more to maintain because of the deteriorat-

Fig. 1(a). Indoor plant for processing volatile, inflammable organic solvent.

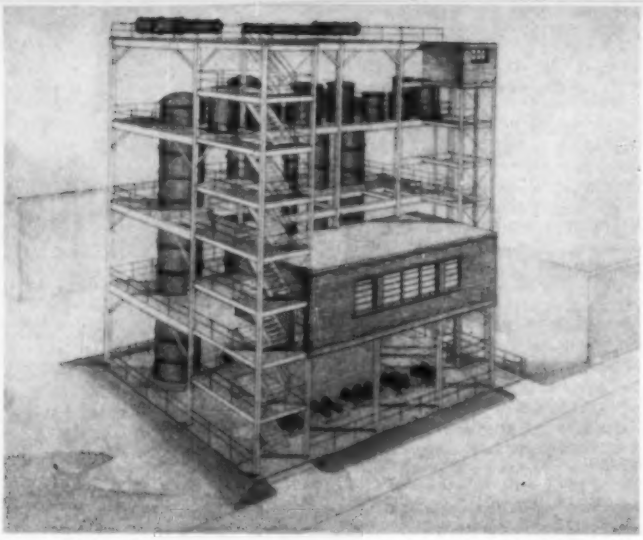

Fig. 1(b). Plant shown in Fig. 1(a) designed for outdoor construction.

ing effects of weather on outdoor facilities; and, for short periods, inclement weather could hamper seriously, or even prevent maintenance on outdoor units. However, outdoor design allows greater accessibility to the equipment, making possible the removal of large pieces of equipment, heat exchangers and pipe sections, as units for shop-servicing. Similarly, the outdoor plant usually surpasses its indoor equivalent in ease of expansion, since there are no confining walls to be removed.

3. *Operating Costs.* There is usually no significant difference in utility, operating labor and other such costs between indoor and outdoor plants.
4. *Safety.* Where fire, explosion, or fume hazards are present, outdoor plants reduce these risks markedly, because dangerous vapors can disperse rapidly into the atmosphere.

Figures 1(a), 1(b), 2(a) and 2(b) illustrate some of the salient architectural features of indoor and outdoor construction. Pictured are two plants, each designed for both types of construction.

Figure 1(a) shows an indoor plant for processing volatile inflammable solvents. The vertical shaft on the left of the structure encloses a stairwell; the column on the right, a passenger elevator. The pumproom is located at the center front on the ground level; the control-room, directly over it. The main processing equipment takes up the high back part of the building where the first, second and fifth floors are concrete slabs; the third and fourth, steel grating.

Figure 1(b) shows the same plant as it would be designed for outdoor construction. In this instance, a study indicated that there was nothing to be gained in changing the arrangement of equipment from the indoor type. Hence, the structural arrangement remains the same except that the roof has been removed, as well as the walls, and the concrete floor on the fifth level has been replaced by steel grating. The concrete floor on the second level, which has been left in, now provides overhead shelter for the process and transfer pumps on the ground floor.

Figure 2(a) illustrates an indoor plant for producing an organic chemical, freezing above normal room temperature, from volatile and inflammable organic raw materials. The main processing equipment is arranged in two banks in the high part of the building. The control panels are located on the second floor center aisle, between the two banks. The process pumps are on the ground level, beneath the process equipment and near the intermediate process tanks, which are arranged in one-story bays extending the full length of the building on each side. Access to the upper levels is provided by an enclosed stairway up the front of the building, and by an interior stairway in the back of the structure.

Figure 2(b) shows this plant designed for outdoor construction. In this case, a study showed that it was necessary to rearrange the equipment in order to provide the most efficient plant layout at the lowest cost. The space between the two banks of equipment was increased to allow the intermediate process tanks to be placed in the center bay on the ground level. This resulted in sufficient room on the second floor to allow the control-house to be centrally located in the structure. The full-width concrete slab forming the second floor provides overhead shelter for the pumps and tanks on the ground level.

In Table 1, a breakdown of total direct labor and material cost of two plants, each designed for indoor and outdoor construction, is shown to illustrate the distribution of costs in two particular cases. For each plant, component items represent costs per $100 of cost of the corresponding indoor plant. In both cases there is no change in the cost of process equipment, and only a slight increase in the cost of piping for the outdoor-type plant. Although in other cases piping cost may increase more in moving a plant outdoors, in the examples cited most of the process lines require the same treatment, as far as steam-tracing is concerned, inside or outside. The decrease in the item "Structures," which also includes foundations and buildings, for outdoor over indoor, reflects principally the cost of the enclosure, amounting to $8.1 in the case of Plant A, and $12.3 for Plant B, per $100, of respective indoor plant cost. This is the principal saving in outdoor construction.

The increase in insulation cost for the outdoor plant also shows considerable variation; $0.4 for Plant A, and $2.6 for Plant B. The reason for this is the fact that most of the equipment in Plant A had to be insulated for indoor installation, while in Plant B many of the columns, exchangers and tanks, which did not require insulation indoors, had to be insulated when installed outside. An increase in insulation thickness also contributes to higher outdoor insulation cost. Where the indoor plants were designed for a minimum temperature inside the buildings of 60° F., the rigorous winter conditions assumed require an outdoor design temperature of —20° F. This change in design temperature necessitates some increase in insulation thickness, but since the labor cost for installing insulation usually accounts for more than 50% of the total insulation cost, necessary revisions in thickness have only a small effect on total plant cost.

The electrical item shows a small decrease in moving the plants outdoors because vapor-tight lighting equipment could be used outdoors in many locations where safety considerations would require the use of the more expensive explosion-proof-type inside buildings.

The sum of the cost items in each case is, in effect, the cost of the plant as per cent of indoor plant cost. Thus, Plant A, when built outdoors, will cost only 92% as much as when built indoors. The difference in the case of Plant B is 10.5% of the indoor plant cost.

As in the case of Plant A, the increase in insulation and piping costs for outdoor plants usually almost bal-

TABLE 1.—COMPARISON OF INVESTMENT COST DISTRIBUTION FOR INDOOR AND OUTDOOR PLANTS

	Plant A		Plant B	
	Dollars per $100 of Indoor Plant Cost			
	Indoor	Outdoor	Indoor	Outdoor
Process equipment	51.6	51.6	42.5	42.5
Piping	16.5	16.6	15.8	15.8
Structures	19.5	11.4	32.6	20.3
Insulation	6.0	6.4	2.4	5.0
Electrical	4.8	4.6	4.5	4.2
Miscellaneous	1.6	1.4	2.2	1.7
	100.0	92.0	100.0	89.5

ances the decrease in electrical and miscellaneous costs. Hence, the structural cost differential between indoor and outdoor plants normally approximates the difference in over-all plant cost. This condition is inherent in conclusions drawn later as to average plant cost differentials. However, in cases such as Plant B, where the amount of equipment surface requiring insulation increases greatly when the plant is installed outdoors, detailed knowledge of the process is required to apply the appropriate correction.

In seeking a basis of comparison between the costs of indoor and outdoor plants, it was found that a fairly good correlation could be obtained by plotting the "structural percentage" vs. the direct plant cost. The structural percentage used here is defined as the labor and material cost of all buildings, supporting structures and foundations, expressed as a percentage of the direct plant cost. In turn, the direct plant cost is defined as the cost of equipment, materials and labor to construct the plant, and does not include the cost of such items as engineering, drafting, construction tools, etc.

In examining the data used for this work, several variables were found which could not be correlated satisfactorily, such as:

1. The type of process as it affects the ratio of process equipment cost to total plant cost. For example, plants containing a large proportion of alloy equipment usually have a lower structural percentage than those containing predominantly steel equipment.
2. The sharpness of the line of demarcation between the indoor and the outdoor plant. Semi-enclosed plants have been excluded from this paper. Plants considered herein are either of the totally open or completely enclosed type.
3. The structural percentage for plants costing less than $500,000. Attempts to correlate data on plants in this range were so inconclusive that these have been omitted from this paper.

It is such factors as these that are usually responsible for the marked variation of particular points from the general data trend.

Figure 3 presents the data obtained from a study of 14 selected chemical plants. The points representing outdoor plants are shown as open circles; those representing indoor plants, as solid circles. The delta points represent data on eight petroleum refinery units which were investigated to see if they confirmed the general data trend. The points used to draw the curve are indicated by double circles. The numbers opposite each point refer to the data given in Table 2. Where possible, job costs were used in calculating the data, but in many cases data were obtained from the latest available estimates.

The abscissa is the direct plant cost, expressed in millions of dollars, and the ordinate is the structural percentage. The lower curve represents an average of data for outdoor plants; the upper curve, data for indoor plants. The difference in structural percentage between indoor and outdoor plants, as represented by the vertical distance between the curves, varies from about 11% at $500,000 of direct plant cost, to 9.7% at $5,000,000. As previously mentioned, this difference approximates the direct cost differential between indoor and outdoor plants. However, in order to obtain the cost differential as a percentage of indoor plant cost, it is necessary to multiply the differential percentage obtained from the graph by a factor of 1.12. The resulting figure will then be the percentage of indoor plant cost to be saved by outdoor construction, e.g., 12.3% at $500,000, and 10.9% at $5,000,000 of direct indoor plant cost.

TABLE 2.—STRUCTURAL PERCENTAGES AND DIRECT COSTS OF CHEMICAL PLANTS AND PETROLEUM REFINERY UNITS

Case No.	Direct Cost	Structures as % of Total Cost
Outdoor Chemical Plants		
1A	$ 654,000	22.7
2A	1,201,000	12.4
3	5,661,000	12.5
4	2,055,000	13.7
5	2,000,000	13.3
6	1,248,000	14.7
7	954,000	18.9
8	841,000	23.5
9	733,000	25.4
10	577,000	15.4
Indoor Chemical Plants		
1B	$ 730,000	32.6
2B	1,309,000	19.5
11	4,641,000	21.3
12	1,509,000	24.9
13	1,337,000	33.0
14	1,067,000	27.5
Outdoor Petroleum Refinery Units		
15	$5,813,000	17.9
16	2,910,000	13.2
17	2,865,000	18.1
18	2,658,000	11.6
19	1,875,000	16.3
20	1,529,000	15.9
21	1,310,000	17.6
22	623,000	24.9

Fig. 2(a). Indoor plant for producing an organic chemical freezing above normal room temperature.

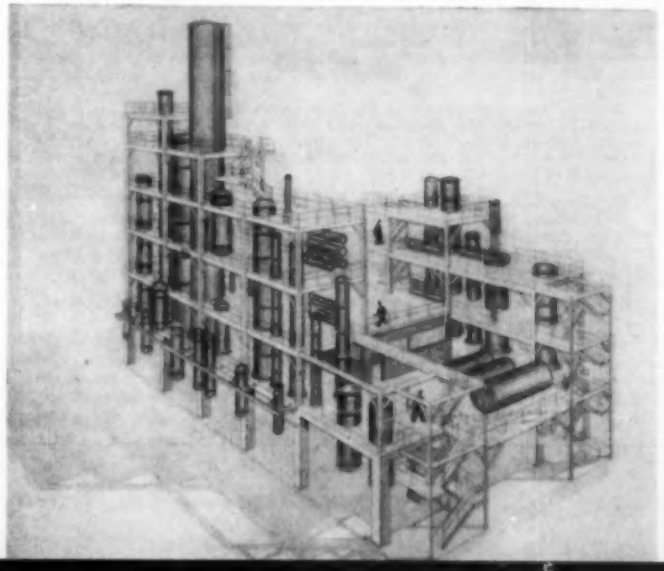

Fig. 2(b). Plant shown in Fig. 2(a) designed for outdoor construction.

An examination into the causes for deviation of specific data points from the average curves brings to light some interesting facts:

1. The displacement of points *2A* and *2B* below their respective curves is due largely to the high proportion of alloy equipment used in these plants—far above average. In spite of this, the differential of 7.1% between their respective structural percentages is in fair agreement with the 10% interval between the average curves at this point.
2. Point No. 10 exemplifies an organic chemical plant with an unusually high proportion of highly specialized and expensive process equipment. The depression of the structural percentage caused by the high process equipment cost is accentuated by the minimum use of structures and the absence of pump shelters.
3. Point No. 13 represents a pharmaceutical plant which is characterized by a disproportionately high cost of enclosure. Parts of the building had to be designed to meet special air conditioning and cold storage requirements.
4. It is to be noted that in general the delta points, representing petroleum refinery units, fall above the curve for average outdoor chemical plants. Use of a higher proportion of carbon steel equipment in petroleum refineries than is commonly used in chemical plants decreases the structural percentage by decreasing the total plant cost without affecting the cost of supporting structures. However, point No. 18 is an exception to this situation since it lies slightly below the average curve for outdoor chemical plants. It represents a crude oil topping and vacuum distillation unit in which much of the equipment is large enough to be self-supporting. The consequent decreased structural steel requirement lowers the point.

It is evident from the nature of the deviations encountered that the curves on Figure 3 represent averages for indoor- and outdoor-type plants. Another set of data might show the curves to be displaced somewhat from the positions shown, but the interval between the curves is expected to be more constant than their absolute positions.

Summary and Conclusions

The relative merits of indoor and outdoor chemical plants in areas having appreciable severe winter weather and normal rainfall are reviewed. If a process is adapted to outdoor construction, the properly designed outdoor plant will have the important advantages of lower first cost, decreased fire and explosion hazards and greater facility of major repairs and expansion over the corresponding indoor type. The principal difference in first cost between the two types was found to be the enclosures themselves, with somewhat higher insulation cost, and slightly lower cost of electrical work occurring in outdoor plants.

Though this paper confines itself to plants which conform closely to completely indoor and outdoor design, the partially enclosed plant has much to offer for certain processes in which some steps require enclosure while others may be left outdoors. In these cases it is possible by the judicious use of enclosures to obtain economy and safety features, combined with convenience of operation, which surpass both totally enclosed and fully open plants.

A plot of the percentage of direct plant cost chargeable to structures, buildings and foundations vs. the direct plant cost for 14 chemical plants showed that over the range from $500,000 to $5,000,000 of direct plant cost, there is an average differential of 10% between the indoor and the corresponding outdoor type. Plotted cost data on seven petroleum refinery units are in substantial accord with the trend of the chemical plant curves.

The above 10% differential is not, however, the cost difference between indoor and outdoor plants. Application of a factor of 1.12 to the 10% structural differential figure is necessary in order to convert it to the percentage of indoor plant cost which may be saved by outdoor construction, i.e., 11.2%. This cost differential applies for average plants. It may vary substantially in specific cases and should be checked when exact figures are required. In many cases, the other advantages of outdoor design, together

Introductory Remarks by J. R. Minevitch, Chairman of the Indoor vs. Outdoor Chemical Plant Construction Symposium

It has been the general custom to house chemical plants in totally enclosed-type structures, particularly in climatic regions where extremes of cold and wet weather prevail. This trend is gradually being reversed in the direction of outdoor-type installations, as evidenced by the increasing number of such plants constructed in recent years. Experience over a period of years in the successful functioning of petroleum refineries and certain types of chemical plants, designed and constructed with open-type structures to operate under varying weather conditions, has accelerated this trend and five principal factors have been largely responsible.

1. Sound and accepted designs for continuous operations on a 24-hr. a day basis and for uninterrupted service of many months' duration.
2. Wider selection of high quality materials of construction; advances in design and fabrication of process equipment.
3. Advances in the design of automatic instrumentation and of remote controls, with central control stations for all operations.
4. Trends in the direction of larger-scale operations and of higher unit capacity plants.
5. Continually rising costs of materials and labor, resulting in excessive construction and investment costs for processing facilities.

Today's high construction cost of plants is in the main due not only to high prices for materials and labor but also to present-day demand that such plants be designed and constructed for maximum operating efficiency at minimum interrupted time. The effect of such high costs is burdensome from an investment standpoint and is particularly so on the economics of new chemical manufacturing projects. This situation has been a challenge to the chemical engineer in his continual search for ways and means of decreasing over-all plant investment costs.

A great deal has already been accomplished in this direction of lower costs through application of correct process engineering principles, through general simplification of equipment and piping designs and through more efficient methods of field construction. Management, however, insists that further reductions in plant costs are necessary for balanced and more profitable operations.

Outdoor-type chemical plants can advantageously be installed for many processes in Canada and Michigan, with their long winters, as well as in California and on the Gulf Coast. The outdoor-type plant has many advantages and, if a process is adapted to outdoor construction, the properly designed outdoor plant will show:

1. Lower first cost by as much as 10%-12%.
2. Decreased operating hazards from toxicity, fires and explosions. Natural air currents and lack of confinement tend to dissipate any accumulation of vapors quickly and reduce the concentrations to a point where these are harmless.
3. Greater facility for plant extensions and expansion.
4. Lower over-all costs of maintenance and repairs, contrary to accepted opinion.

The operating and economic advantages of the outdoor plant are many and we, as engineers, must give more serious consideration to this subject in the immediate future. Design engineers and operating personnel must revise their thinking in order to overcome unwarranted opposition to the outdoor-type chemical plant installations.

with the investment cost saving, will make outdoor construction attractive for new chemical plant facilities.

Acknowledgment

The authors wish to express their appreciation of the valuable assistance and suggestions rendered by other members of the Badger engineering staff in the preparation of this paper, and are especially grateful to C. Poehler of the drafting department, who prepared many of the illustrations.

Discussion

J. R. Minevitch, presiding

A. J. Pastene (Monsanto Chemical Co., St. Louis, Mo.): This question is addressed to any or all panel members—For an outdoor installation in colder locations, are you using or would you hesitate to use any considerable amounts, or large-sized units, of porcelain, rubber-lined, glass, or glass enameled items?

W. H. Williams (Dow Chemical Co., Midland, Mich.): We, at Dow, have used all of those materials in outdoor installations. The glass-lined equipment is used without any hesitation or preparation, but the stoneware, porcelain and glass equipment must be more carefully installed to take care of temperature changes for more expansion. More care must be taken to prevent damage from falling objects, such as ice.

J. R. Minevitch: Mr. Mullen, have you anything to add to that?

L. T. Mullen (Du Pont Co., Wilmington, Del.): I have not had any direct contact with an outdoor plant using those types of materials. However, the company has built plants using glass pipe and glass equipment. I shouldn't think the problem would be any more difficult than supporting lead pipe or lead equipment for protection from breakage, as has been mentioned. I don't think it insurmountable at all.

J. R. Minevitch: Mr. Kieweg?

Homer Kieweg (Commercial Solvents Corp., Terre Haute, Ind.): We have used glass-lined and glass equipment without any difficulty. We have not used any stoneware recently, but have had no trouble whatsoever on the glass-lined equipment or on the glass piping on an outdoor installation, as far as exposure is concerned.

W. A. Carlson (General Mills, Inc., Minneapolis, Minn.): Concerning the handling of liquids in outdoor plants—mention was made of disadvantages in the handling of solids. Even in plants where a liquid is the primary material handled, it is often necessary to handle solids, and I wonder if conveyors, for

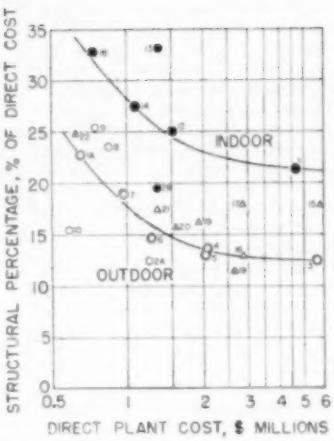

Fig. 3. Structural percentage vs. direct plant cost for indoor and outdoor chemical plants.

example, are sometimes insulated or steam-traced to prevent free moisture from condensing on the inside and freezing up that type of equipment?

Homer Kieweg: We have handled solids in conveyors but primarily in somewhat warmer climates. However, the same method of handling, I think, would apply in colder climates, as well. In that case we have steam-traced, and in the case of screw conveyors, we have actually installed steam lines within the conveyor itself, just above the curve of the ribbon, so as to keep down the amount of condensation forming within the conveyor.

My reference to the solids did not apply to the handling of solids in a continuous manner but rather had to do primarily with cases in which it was necessary to charge solids into the manhole of a vessel for a batch process under such circumstances that the expense of installing conveyor equipment for moving those solids from a warehouse location to the outdoor equipment was not warranted.

In the case of a continuous-handling process, I see no reason at all why it cannot be done, but in that case it is merely a matter of economics.

J. R. Minevitch: I have some written questions, several of them addressed to one or more speakers. I have one from E. E. Mohr, Eastman Kodak Co., Rochester, N. Y.—Generally speaking, do you believe that outside installations lend themselves best to: (1) continuous rather than batch operations, (2) expected long-life installation rather than short-life, (3) installations in which many changes will probably be made, and (4) handling liquids rather than solids. Why?

Mr. Williams, do you wish to try to answer any of these?

W. H. Williams: (1) I believe outdoor installations lend themselves better to continuous rather than batch operation. In the case of batch operations, I believe that generally speaking indoor operations are to be preferred, provided the hazards and costs are not increased substantially.

(2) I do not believe we have ever considered long-life installation versus short-life.

(3) The changes are just as easy to make in the outdoor as in the indoor plant, if not easier. However, if you are handling materials which freeze under outdoor but not under indoor conditions, there might be some advantage in indoor conditions for short-life operations.

(4) Handling liquids in outdoor installations is easier than handling solids, in my opinion.

J. R. Minevitch: I have other questions from the same gentleman—Would any of you care to make any suggestions concerning satisfactory types of construction about: (1) weather protection of insulation where the installed unit emits heat, (2) weather protection of insulation including vapor barrier, where the temperature of the installed unit will be lower than outside dew point?

Homer Kieweg: I have only one comment to make in that respect, and that is—insofar as we are concerned, I think we would say definitely that the maintenance of insulation is one of the major considerations we have encountered in outdoor constructions. We have not yet found what we would call the ideal application of insulation which will reduce maintenance to the figure we think it ought to be. Insulations have a habit of deteriorating for one reason or another and to that extent we are continuously on the lookout for better ways of handling insulation.

I'll admit that in a lot of cases the failure of insulation is probably due to carelessness on the part of either the operators, the maintenance men, or the like, rather than the materials themselves. If an installation is so made that in the changing of a pipe line or in getting to parts of the equipment, operators will prefer to walk on insulation, provision must be made then so that they can walk on it. Otherwise it is bound to deteriorate, but I would not want to answer the question directly. Insulation is really a problem.

J. R. Minevitch: Mr. Williams, would you like to elaborate a little bit on insulation?

W. H. Williams: We use various protective coverings on insulation. The usual one is 3-ply roll-roofing. In places where the insulation is subject to me-

chanical wear or rough treatment we use galvanized iron sheeting, and in other cases, where we have only weather conditions to contend with, we will use the tar or "plastic coatings" put out by various companies for sealing and covering insulation.

E. E. Mohr: What of the weather protection for insulation where the temperature is lower than the outside dew point?

W. H. Williams: For insulation on refrigerated equipment we use Styrofoam, insulating cork, or hair felt. For the vapor seal we use the waterproof cements or "plastic" seals sold for this purpose. If a wearing surface is required, we will cover the cement coating with galvanized iron sheet.

E. E. Mohr: In the case of cold insulations, I see no real difference in the problem whether the equipment is indoor or outdoor as far as provision of a vapor barrier is concerned. In other words, it is only a matter of time until the barrier is broken and moisture pickup occurs, and in many cases I doubt whether it would be any faster outdoors than indoors.

J. R. Minevitch: Dr. Kemp, a question to you—Why did you decide to leave ether tanks above ground rather than bury them?

H. S. Kemp (Du Pont Co., Wilmington, Del.): I see no real necessity for burying them. We keep the vapor pressure down in the summertime by turning on water sprays and allowing water to trickle over the tanks. It's cheaper to put in a few concrete piers than it is to dig a pit. We have no particular reason for wanting to bury them. We'd rather have them up where we can see them.

J. R. Minevitch: Mr. Williams, a few questions to you—How do you cope with hazards of personnel slipping on icy walkways and platforms during foul winter weather?

W. H. Williams: As a rule we use steel grating for the walkways and stairs. Where we have a solid or continuous floor, we use concrete or checker-plate. We shovel the snow and remove ice with calcium chloride and of course we guard openings with the usual railings and toe plates.

J. R. Minevitch: Another one for you from Mr. Keller of American Cyanamid Co.—Can you elaborate on the Dowtherm pipe-line jacketing you mention? If condensing vapor was used, what means of trapping for condensates was utilized?

W. H. Williams: We would use ordinary steel steam traps, with the proper-sized hole in the disc, on vapors at differentials above 10 lb./sq.in. With low differential pressures, a barometric seal will handle Dowtherm vapor and condensate adequately. Of course, with liquid Dowtherm you need no trap. We would use either liquid or vapor, dependent on the temperature we wish to maintain. It is simply a case of enclosing one pipe inside another, for example, a 2-in. inside a 3-in. one.

J. R. Minevitch: Mr. Lane of the Upjohn Co. asks Mr. Williams—In companies where you have both indoor and outdoor plants, do you have personnel problems in getting operators and maintenance men to work on the outside plants?

W. H. Williams: We have few. As I said, we try to eliminate major repair jobs during the coldest weather and we have shut a piece of equipment down for as long as 24 hrs. in severe weather rather than try to get a crew to repair it. In the past 15 or 20 years, I believe, there have been only two or three such occasions. There has been no difficulty in getting crews for operating outdoor plants.

J. R. Minevitch: Mr. Williams, another one for you—Do you have any fixed fog or sprinklers for fire protection on your outside installations? The question was posed by Mr. Guthrie of Minnesota Mining & Manufacturing Co.

W. H. Williams: We do on Class I materials—we have used sprinkler systems, especially in cases where the liquid sinks. In cases where the liquid will float, as in the case of benzol, we have more recently installed the fog system. The object of these systems is primarily to keep the steel cool and prevent it from collapsing, as well as to put out the fire.

J. R. Minevitch: Are temporary shelters provided for maintenance personnel when working outside for several hours in extremely cold weather?

W. H. Williams: They are provided. We erect temporary scaffolding and cover it with a fireproof tarpaulin where barehand operation is necessary.

J. R. Minevitch: R. S. Foster of General Mills asks—What troubles have you encountered of rain or moisture getting into openings in insulation which occur due to the difference in expansion of metals and insulation in high temperature operations? Mr. Mullen, have you any comments?

L. T. Mullen (Du Pont Co., Inc., Wilmington, Del.): Our particular installation cannot be considered as a high temperature job. We haven't had any more difficulties than you would have with an indoor installation. Definitely insulation problems are greater; they probably always will be, but I haven't heard of any particular reaction to that condition.

W. H. Williams: I think I can agree with Mr. Mullen. The insulation is soft enough and capable of taking care of expansion in all cases that we have actually come up against, so I don't believe we can claim there is any real difference between the outdoor and indoor preparations for that. For instance, where you are handling caustic at 400° C. it doesn't make much difference whether it is indoor or outdoor.

Homer Kieweg: The only thing I can add is that the use of a properly lapped shield over insulation will usually take care of the slight break that may occur, in the case of expansion due to heat on the lines themselves, and protect them from the weather to keep the moisture from getting in. We have not encountered it as a particular problem.

J. R. Minevitch: Mr. Keller, have you anything to add to this review here, in view of your recent experience in operating an outdoor plant insulated for about 600° F.?

F. R. Keller (American Cyanamid Co., New York, N. Y.): I assume you are speaking specifically of the reaction of the insulation to the weather. Concerning that particular plant, we experienced practically no difficulties with insulation deteriorating, except from a mechanical source. That insulation was protected with a conventional mastic finish. It was a Foamglas job and the mastic finish that was put on was perfectly satisfactory.

J. R. Minevitch: A question by L. P. Scoville of Jefferson Chemical Co. to any of the speakers—Do you find it necessary to consider the use of low temperature steels for equipment installed outdoors in very cold climates? I am thinking of low Charpy impact values.

W. H. Williams: We have never considered that necessary, because the periods are of short duration and the chances for impact on ordinary types of equipment are very unlikely. If we had a problem where we were depending on continual impacts, it might be worth considering. We do use the low-temperature steels where we are operating any equipment at continually low temperature.

J. R. Minevitch: The next question is—Is there a time-saving factor in the construction of an outdoor plant? Would any of the speakers care to comment? The question is from B. S. Lane of the Upjohn Co., Kalamazoo, Mich.

I can say that in our experience, from the standpoint of design and construction of such a plant, there is a definite time factor, particularly today. For instance, at the present time it takes five months to get common brick, and, of course, bricklayers are rather expensive men these days. Normally, however, it is doubtful whether a properly scheduled job would show any substantial saving in time. In any case, you would have more to purchase and more work to do.

Mr. Williams, could you comment on what your experience has been?

W. H. Williams: Our experience indicates that an outdoor plant saves engineering and purchasing time, as you have mentioned. How much over-all saving in construction time is realized will depend upon deliveries of equipment, and these deliveries may be so long that little time is saved by reducing the building requirements. The actual labor required for an outdoor vs. indoor plant, exclusive of the building, seems to be very much the same as far as we can see. The outdoor plant does not develop any labor problems in construction over the indoor and, in case of expansion or maintenance, it reduces those problems. That was brought out by Mr. Kieweg.

J. R. Minevitch: Here is a question from Mr. Stell of Goodyear Tire & Rubber Co., Akron, Ohio—Are there any installations that any of you know of in which the product requires indoor construction but which are designed so that large doors on all sides of the enclosure can be opened in case of serious spill of flammable vapors or liquids? If so, what is the design?

I am not sure that I understand the question, but I know of a design of an open-type plant in which most of the pumps requiring frequent attention are located on the ground floor. On that floor there are sliding doors on all four sides for the protection of the operators against inclement weather conditions. In most cases, however, sliding doors are of doubtful value.

I assume that you could design a one-story indoor type of plant with sliding doors. Would that be the interpretation of the question, Mr. Stell?

R. C. Stell (Goodyear Tire & Rubber Co., Akron, Ohio): We are considering putting sliding doors on two floors.

Anonymous: Back in 1920 we thought that we needed an enclosure around such a plant. Since then we have found it unnecessary. But at that time (and the plant is still running) we built a brick first floor where the operating personnel were housed and a concrete deck without any holes in it, above the first floor, and then we erected the other equipment above that concrete deck under a roof of corrugated iron with side walls of corrugated iron hung from hinges at the top or at the plate. One time during the thirty years the high wind carried the side walls away and another time we had a minor explosion which lifted them.

J. R. Minevitch: Mr. Stell, does that answer your question?

R. C. Stell: Not entirely, but it gives me some idea of what we might expect if we went to this construction.

J. R. Minevitch: Mr. Kieweg?

Homer Kieweg: For one thing, if something occurs where the flammable vapors escape, as has happened, it may be too late to get the doors open; so the thing to do is to leave them off in the first place, if it is at all possible.

J. R. Minevitch: It seems, Mr. Stell, that the consensus on this side is for you to make it outdoors.

Are there any other questions?

Zola G. Deutsch (Deutsch and Loonam, New York, N. Y.): I have one minor question concerning the second paper. It is stated that when the steam tracer lines were inadequate, a steam hose was used to melt the product in the pipe lines. The paper doesn't make clear just what type of tracer lines was used. A common type is the "gut-line," usually a small pipe line supported near the axis of the product pipe line which is lagged in the usual manner. The other type of tracer is a small steam line external to the main pipe line, but enclosed in the same lagging. In all cases, lagging protects the outside of the pipe. Will the speaker please explain how the steam hose is used for these types of construction?

L. T. Mullen: Well, in handling glacial acetic acid with its high freezing point, I think we'll admit that is a somewhat unusual case for outdoor construction. We use double tracer lines on each line handling glacial acetic. There were some freeze-ups at ends of lines, and the judicious use of the steam hose referred to was just exactly what it implies—it was turning live steam onto the pipe in order to melt the slush down the same way as I've seen them thaw out a trap with a blow torch. Crude but effective—that's all I can say.

Zola G. Deutsch: Do I understand that the lines are uninsulated?

L. T. Mullen: No, they are insulated and steam-traced.

Zola G. Deutsch: Then you simply blow the steam against the insulation?

L. T. Mullen: Against the insulation—that's correct.

Zola G. Deutsch: Along this same line of discussion, I am not sure what I propose is applicable where there is considerable fire hazard. I have found that a valuable technique is to have a readily portable welding machine in the plant, which can be brought to the scene of pipe-line trouble and connected to lugs which are welded to the pipe and come out through the insulation. We have found this technique to be simple and effective.

L. T. Mullen: We've learned a lot about steam-tracing and insulation of outside lines. I have observed the plant when a cold rain would come up and have seen the needle on the steam flowmeter creep up where we thought we had applied insulation generously. We found we could have put a little more on. But that is the case during a rain much more than a cold wind. The steam flow will jump up with a cold rain as it washes down the insulation.

J. R. Minevitch: I have a few more remarks to make. This whole symposium brings out the fact that the progress of our thinking and experience has more to do with the acceptance of the idea of outdoor-type construction than actual conditions. We are gaining more confidence in less costly and more efficient types of construction, and consequently progress is evident.

Zola G. Deutsch: The structural skeleton of the outdoor type of plant is similar to the skeleton one normally uses on the housed design. I believe that we, as chemical engineers, are guilty of a slow break with tradition when it comes to designing a plant to be an outdoor plant all of its life. The modern designs of outdoor plants are quite dissimilar to cement plants or blast-furnace plants which are traditionally unhoused. I am sure that no one in this audience has ever seen an enclosed cement plant or blast-furnace plant. In such plants it is common practice to support all runways, platforms and access stages right on the main equipment, especially that part of the main equipment which has a long life and seldom needs dismantling. This points up something that we, as designers of outside plants, have not yet learned: that is, that it pays to design the main equipment for the plants that are intended to be of outdoor design in such a way that they are self-supporting against wind, snow, and other structural loads, as well as capable of supporting access platforms, pipe supporting structures, etc. If we will have learned properly to take advantage of such design economies, I am reasonably sure that savings will be larger than indicated in the papers we have heard today, that is, the savings will exceed 10 or 12%.

I have one last question, and it is directed to the boss of the symposium, or rather whoever it was that gave it the title with the word "versus" in it. Who was to have been the devil's advocate?

J. R. Minevitch: Well, I think if we did it over again we probably would talk just on outdoor plants and use the indoor merely as a yardstick of measurement.

I wish to thank the authors for having worked hard to get the message over. We can all agree that it is principally a matter of basic design and a study of the chemical and physical properties of the particular chemicals which are being handled; and the closer the chemical, physical properties are evaluated, the more nearly the correct design will be attained.

CATALYST EVALUATION AND MIDDLE OIL PREPARATION

In An Experimental High Pressure Coal Hydrogenation Plant

Part I

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Plant equipment and layout of a coal hydrogenation pilot plant of the Bureau of Mines are described in detail, together with a discussion of methods for operating the plant and evaluating the data obtained. Five operating runs at 460° C. and 3500 lb./sq.in. with 35% coal paste are reported. Results produced in liquid phase hydrogenation of bituminous coal by tin, zinc, nickel, and iron catalysts and also in the absence of any added catalyst are compared. The exceptional activity of tin catalysts, heretofore regarded as unique for this reaction, could be closely duplicated in regard to liquefaction and "asphalt" formation by nickelous chloride catalyst impregnated on the raw coal from aqueous solution. Operation in a simulated recycle manner to produce middle oil from Rock Springs coal using tin catalyst is also described.

THE Bureau of Mines has been studying catalysis in liquid phase coal hydrogenation at its Synthetic Liquid Fuels Research and Development Laboratories at Bruceton, Pa. Although tin compounds are outstanding catalysts for hydrogenation of bituminous coal, their short supply and high cost make them impractical for large scale use in the United States. In Germany, high pressure bituminous coal hydrogenation plants used iron catalysts at 700 atm., although tin oxalate was generally employed for operation at 300 atm. (*2*). The objective of the Bureau program has been to find catalysts which would perform better than tin compounds, preferably at lower operating pressures, and which were both cheaper and more available in this country than tin.

Initially, materials were tested for catalytic activity in small autoclaves (*6*) while attempting to analyze liquid-phase coal hydrogenation mechanism so that catalyst development could be planned on a more rational basis (*4*). As promising catalysts were found in these studies, they were later investigated in the continuous experimental plant.

The present paper reports the results obtained in this plant at 3500 lb./sq. in. gage, at 460° C., on Rock Springs coal with tin, zinc, iron, and nickel catalysts. In these tests the principal product was heavy fuel oil, similar to Bunker C or A.S.T.M. grade 6; however, in certain operating periods a solids-free distillable middle oil was the main product. In addition to catalyst evaluation, this paper describes techniques which have been evolved for treating and interpreting pilot plant data, in order to make the various tests mutually consistent. Certain aspects of equipment development are discussed in detail.

As a result of certain data obtained in these experiments, a re-evaluation of earlier (*3*) low pressure hydrogenation work was begun. Successful hydrogenation of bituminous coal to heavy fuel oil was achieved at 1500 lb./ sq. in. gage. This development is especially promising in view of the potential reduction in construction and operating costs. These low pressure runs will be reviewed in a subsequent paper of this series.

Experimental Conditions. The tests reported here were pilot plant evaluations of certain catalysts; in particular, comparisons of "new" catalysts with tin, generally regarded as a satisfactory catalyst for liquid phase hydrogenation of bituminous coal. To compare results with different catalysts satisfactorily, the catalyst testing method had to be quite reproducible, and in each test the plant had to be relatively free of any previously tested catalyst. These conditions were quite well satisfied. In each run, new, clean, liners were fitted to the converters.† The liners, made of 2-in. extra-heavy, low-carbon steel pipe, facilitate the cleaning of converters at the end of a run and enable the attaining of higher space velocities with available pumping facilities. Each lined converter has a 2.63 sq. in. free cross section and a liquid capacity, to the overflow standpipe level, of some 200 cu. in. Thus, each run was started with clean, reasonably reproducible, and uncontaminated steel surfaces in the hot reactor zone. Tubing lines in the hot high pressure system ordinarily remain clean; those that are partially plugged are replaced. Prior to each run on a new catalyst, the paste-mixing tank, paste weigh tank, and heavy oil receivers were cleaned as well as possible. In addition, for the "no catalyst" run, these tanks were practically scoured clean, and most of the low pressure pipe replaced.

In liquid phase coal hydrogenation large quantities of recycled product oil (or the heavy nonvolatile part of this product) are used as a vehicle in which the coal is suspended. If the tests reported here were performed with recycle

Part II of this paper will be run in an early issue of Chemical Engineering Progress.

† Plant flow sheet and equipment are discussed in detail in Part II.

TABLE A

Ultimate Analysis, wt. %		Distillation, A.W.P.A.† wt. %	
		° C.	
C	91.5	0-210	0
H	5.2	210-235	0
N	1.1	235-270	1.6
O	1.7 (difference)	270-300	4.2
S	0.6	300-310	5.7
Ash	.1	310-355	7.9
		Benzene insolubles	10-12%
		Asphaltx ‡	26-30%

† American Wood Preservers Association method.
‡ Benzene soluble but n-hexane insoluble material.

oils obtained from earlier runs with, say, tin catalyst, as initial vehicle, enough tin would be introduced into the system to obscure the effects of the new catalyst. To avoid this difficulty, runs with new catalyst were started with a tin-free, high temperature by-product coke-oven tar * having the average properties as shown in Table A.

The insoluble and asphaltic material in the tar are easily hydrogenated; hence, the first few batches of each run, in which this hydrogenation occurs, are not exactly comparable to subsequent batches. However, final steady state or "equilibrium recycle" conditions for each catalyst are comparable.

The same coal was used throughout. It was a high volatile C bituminous coal of the Rock Springs bed (D. O. Clarke Mine, No. 9 bed, Superior, Wyo.) with the typical ultimate analysis as shown in Table B.

The coal was so ground that 90% passed through a 200-mesh sieve. All the tests of run B-3 and tests 1-3 of B-4 were with standard catalyst (i.e., 0.1% SnS and either 0.05% CHI_3 or 0.5% NH_4Cl, based on gross coal) added as finely divided powder to the coal-oil paste in the mixing tank. In the latter part of run B-4, an attempt was made to use metallic powdered zinc instead of $SnS + NH_4Cl$. Run B-5 was without any added catalyst and with a minimum of contamination by earlier catalysts. For runs B-7 and B-8, with ferrous sulfate and nickelous chloride catalyst, respectively, the method of catalyst addition was changed. Instead of adding the dry powder to the paste, the coal was impregnated in a ribbon-type paste-mixer with an aqueous solution of the desired catalyst, dried to about 1-2% free moisture, and then pasted with oil. The impregnation method distributed the catalyst much more effectively than the older method, and some catalysts which had previously appeared to be of low activity when added in bulk form were surprisingly effective when impregnated (*5*). No tests were made on possibilities of catalyst recovery from, say, the centrifuge residue.

* Supplied by Clairton Works, Carnegie-Illinois Steel Corp.

Experimental Results

Test average conditions and yield data based on corrected material balances are given in Table 1. The reported values are generally based on operating periods of at least four to six batches.†

Certain average analytical data on the feeds and products are presented in Tables 2 and 3. No attempt was made in these tests to carry out a process variable study, similar to one reported earlier (*1*). Operating conditions were restricted to rather limited variation, and while the data obtained here are relatively consistent with applicable correlations published earlier, the data by themselves can not be extrapolated because they cover such a narrow range in the primary variables. The data are intended as a measure of comparative catalytic activity, and as such are satisfactory. Methods of calculation of contact time, material balance correction, and the yields reported in Table 1 are discussed in detail in Part II of this paper.

† A batch refers to a single prepared mix of coal and oil paste. The batch size is varied with changes in pumping rate so that approximately 8 hr. are required to pump it into the plant. A test is a chronologically continuous series of batches performed at a steady set of specified conditions including operating temperatures, paste-pumping rate, and type and amount of catalyst. A "run" or "operation" is a group of tests performed in a given plant at a fixed pressure with a single general objective. Runs are almost always separated from one another by complete plant shutdowns during which equipment is overhauled or changed as required. There is no such time lag between the several tests of a single run or between successive batches of a given test.

TABLE B.

	wt. %
C	71.1
H	4.9
N	1.5
O	13.3 (by difference)
S	0.7
Ash	6.3
H_2O	2.2

Interpretation of data from a plant of this type is rendered difficult by progressive but slow variation in "converter burden." Solids from the feed paste tend to settle out in the converters, but are maintained in suspension by agitation provided by gas bubbles rising through the mass. Converter charge viscosity is about one centipoise at reaction temperature and some settling of unreacted coal and other solid matter probably occurs. The solids content of the slurry in the converters thus may increase with time up to some level higher than that in the feed. If this occurs, the average suspended catalyst concentration goes up and certain of the yields vary. In runs B-7 and B-8 the controllable conditions used in test 1 were repeated in test 4 to check this effect.

Data from this plant are further complicated because the vehicle oil, as well as the feed coal, is amenable to hydrogenation and thermal and other degradation. Therefore, some of the soluble

Table 1.- Summarized operating conditions[a] and corrected yield data.

Test No.	Catalyst and promotor used and quantity based on gross coal	Batch periods included	Contact time, hours	Uncorrected material balance, percent	Yields, percent of M.A.F. coal charged						
					Hydrogen absorbed	Hydrocarbon gases	Organic insolubles	Soluble oil	Asphalt	Water[b] and water solubles	
	Operation B-3										
1	0.1% SnS + 0.05% CHI_3	1-28	.43	95.5	4.8	8.3	3.1	79.8	15.5	13.6	
2	"	1-10, 12-17	.31	95.7	4.0	6.8	4.5	82.1	22.9	10.6	
3	"	1-12	.45	95.0	6.7	18.4	0.6	71.3	2.5	16.4	
	Operation B-4										
1	0.1% SnS + 0.5% NH_4Cl	1-8	.41	99.3	6.0	14.6	+1.6	76.0	4.3	17.0	
2	"	1-8	.42	93.6	6.5	16.2	2.0	71.7	2.3	16.6	
3	"	1-8	.77	96.4	8.3	24.9	-5.8	71.3	-16.9	17.9	
4	None	1-8	.84	97.5	8.0	22.4	-5.3	73.1	-8.2	17.8	
5	None	1-4	.40	98.1	5.2	14.0	2.4	75.2	14.2	13.6	
6	0.1% Zn + 0.5% NH_4Cl	1-3	.38	96.0	4.8	17.1	24.7	46.8	3.4	16.2	
7	"	1-8	.78	95.6	6.9	23.0	-1.8	70.9	-1.6	15.2	
8	"	1-4	.40	98.1	3.8	11.7	33.0	44.0	13.1	14.8	
10	0.1% Zn + 1.0% NH_4Cl	1-6	.86	96.6	7.3	30.1	1.6	59.7	0.5	16.1	
12	"	1-4	.63	98.1	5.8	19.5	12.9	58.2	7.2	15.2	
13	"	1-4	.44	93.3	5.0	20.7	23.5	46.5	12.5	14.3	
	Operation B-5										
1	None	1-8, 10	.69	94.7	3.7	11.8	40.7	35.4	1.9	16.0	
2	None	1-9	.91	99.6	3.7	11.1	43.9	31.3	5.4	17.4	
	Operation B-7										
1	Impregnated $FeSO_4$ (1.0% Fe)	1-8	.72	94.8	6.6	18.6	4.1	65.9	0.4	18.0	
2	"	1-8	.48	97.7	5.3	14.5	5.0	72.2	9.2	15.6	
3	"	1-8	.31	95.6	5.0	13.0	7.2	70.6	19.9	14.2	
4	"	1-3	.91	93.3	7.5	27.0	-1.6	60.3	-12.6	21.8	
	Operation B-8										
1	Impregnated $NiCl_2$ (0.5% Ni)	1-8	.97	95.2	9.2	30.6	1.4	59.3	-18.1	15.9	
2	"	1-8	.81	98.4	6.5	22.4	5.6	67.6	3.3	10.9	
3	"	1-8	.35	97.5	4.5	11.3	9.6	74.8	19.5	8.8	
4	"	1-4	.91	102.7	7.0	22.7	-2.0	70.9	-7.0	15.4	

[a] All tests at 440° C. except tests 1 and 2 of B-3, which were at 440° C. Rock Springs Coal, 35 percent in paste, used throughout. Heavy-oil loop temperatures: 150° C. for B-3 tests 1 and 2; 222° C. for B-3 test 3, batches 1-6, and 300° C. for batches 7-8 of this test; 400° C. for B-4, tests 1,2, 3 and 4; 200° C for B-4, tests 5 through 13; 200° C. for all of B-5; and 150° C. for all of B-7 and B-8.
[b] Includes NH_3, H_2S, CO, and CO_2 and is corrected for moisture in feed paste.

Table 2.- Average properties of heavy and pasting oils.

Test No.	Batch numbers	Material	Viscosity S.S.F. 180° F.	Insolubles (total) percent	Asphalt percent	Distillation, percent to 300°C.	Distillation, percent to 355°C.	Ultimates, percent C	H	N	O	S	Ash	H_2O
Operation B-3														
1	1-28	Heavy oil	46	5.8	18.7	8	25	85.4	8.0	1.0	2.3	0.2	2.2	0.9
		Pasting oil	49	4.2	19.1	8	28	87.2	8.2	1.0	2.8	0.2	0.6	–
2	1-10, 12-17	Heavy oil	170	8.1	23.5	6	23	84.1	7.8	1.1	2.8	0.3	2.6	1.3
		Pasting oil	180	7.0	23.2	5	21	86.4	8.1	1.1	3.2	0.2	1.0	–
3	1-12	Heavy oil	26	5.3	13.4	5	28	87.4	8.2	1.0	1.7	0.1	1.3	0.3
		Pasting oil	32	5.4	16.2	4	26	87.9	8.2	1.1	2.1	0.2	0.5	–
Operation B-4														
1	1-8	Heavy oil	430	9.5	22.8	0.4	8	85.2	7.2	1.1	1.6	0.3	4.5	0.1
		Pasting oil	178	7.2	22.3	2	14	87.6	7.7	1.2	2.3	0.2	1.0	–
2	1-9	Heavy oil	575	9.5	22.3	0.9	9	85.4	7.1	1.0	1.7	0.3	4.3	0.2
		Pasting oil	452	6.3	23.0	0.4	9	87.7	7.4	1.1	1.8	0.2	1.8	–
3	1-8	Heavy oil	378	11.6	16.1	0.1	5	84.2	6.8	0.9	1.6	0.3	6.2	0.0
		Pasting oil	281	8.6	19.9	1	13	87.0	7.7	1.0	2.3	0.2	1.8	–
4	1-8	Heavy oil	267	11.7	16.4	0.1	5	84.8	7.0	0.9	1.3	0.2	5.8	0.0
		Pasting oil	256	9.6	17.5	0.8	11	87.0	7.5	1.0	2.2	0.2	2.1	–
5	1-4	Heavy oil	50	7.7	17.9	4	21	85.8	7.6	1.1	2.6	0.2	2.6	0.1
		Pasting oil	49	6.9	17.2	3	14	87.5	7.8	1.0	2.3	0.2	1.2	–
6	1-3	Heavy oil	–	25.8	21.4	4	17	86.0	6.7	1.6	2.2	0.3	3.2	0.0
		Pasting oil	–	19.0	26.6	5	19	87.8	6.9	1.5	2.2	0.2	1.4	–
7	1-8	Heavy oil	122 [1]	9.5	12.4	9	35	87.7	7.7	1.2	2.4	0.2	0.8	0.0
		Pasting oil	168 [1]	12.3	16.1	7	30	88.7	7.6	1.3	1.8	0.1	0.5	–
8	1-4	Heavy oil	451	25.9	18.2	5	23	85.2	6.7	1.5	2.2	0.3	4.1	0.0
		Pasting oil	453	14.8	18.6	–	28	88.2	7.4	1.4	2.0	0.2	0.8	–
10	1-6	Heavy oil	161 [1]	11.6	12.4	8	32	87.7	7.5	1.2	2.0	0.2	1.4	0.0
		Pasting oil	36	12.3	15.1	9	29	88.6	7.7	1.3	1.7	0.2	0.5	–
12	1-4	Heavy oil	43	19.8	15.1	6	28	87.4	7.2	1.3	2.1	0.2	1.6	0.2
		Pasting oil	36	12.0	15.8	8	29	88.6	7.4	1.3	2.5	0.1	0.1	–
13	1-4	Heavy oil	309	25.7	16.5	7	23	86.3	6.7	1.3	2.5	0.2	2.9	0.1
		Pasting oil	–	19.4	15.7	6	26	88.3	7.2	1.3	2.4	0.1	0.7	–
Operation B-5														
1	1-8, 10	Heavy oil	283	30.4	18.4	5	21	86.5	5.8	1.3	1.7	0.3	2.3	0.1
		Pasting oil	119	18.6	24.1	5	22	90.0	5.8	1.2	2.1	0.4	0.5	–
2	1-5	Heavy oil	304	30.7	19.1	2	19	88.9	5.7	1.4	1.5	0.3	2.1	0.1
		Pasting oil	128	17.5	23.4	3	22	90.1	5.6	1.2	2.2	0.5	0.4	–
Operation B-7														
1	1-8	Heavy oil	95 [1]	7.9	15.7	13	34	87.9	7.2	1.2	1.0	0.3	1.8	0.6
		Pasting oil	143 [1]	6.2	20.6	11	30	89.9	6.9	1.2	1.5	0.3	0.2	–
2	1-8	Heavy oil	148 [1]	7.1	16.3	15	34	85.8	7.4	1.3	1.6	0.4	2.3	1.2
		Pasting oil	121 [1]	4.5	17.9	14	34	88.5	7.6	1.2	2.2	0.2	0.3	–
3	1-8	Heavy oil	37	8.7	22.4	14	30	84.4	7.6	1.4	2.2	0.6	2.7	1.1
		Pasting oil	280 [1]	5.5	21.5	15	32	87.0	7.7	1.5	2.9	0.3	0.6	–
4	1-3	Heavy oil	65 [1]	3.7	11.3	24	43	86.3	8.0	1.5	0.2	0.1	1.4	2.5
		Pasting oil	40	4.1	21.5	17	33	86.3	8.0	1.5	3.7	0.1	0.4	–
Operation B-8														
1	1-8	Heavy oil	–	5.8	4.2	22	49	86.1	7.7	0.9	3.0	0.2	1.6	0.5
		Pasting oil	–	4.9	10.8	16	38	89.6	7.2	1.0	1.6	0.3	0.3	–
2	1-8	Heavy oil	62 [1]	5.8	8.3	21	45	85.1	7.9	1.0	3.8	0.1	1.5	0.6
		Pasting oil	56 [1]	3.3	9.5	22	46	88.4	7.9	0.9	2.4	0.2	0.2	–
3	1-9	Heavy oil	25	8.4	17.4	18	34	83.5	7.7	1.2	2.3	0.3	2.2	2.8
		Pasting oil	124 [1]	4.5	15.7	19	38	87.2	8.2	1.1	3.0	0.2	0.3	–
4	1-4	Heavy oil	79	6.0	9.1	21	40	84.7	8.1	1.1	1.4	0.1	2.3	2.3
		Pasting oil	182 [1]	6.4	15.7	31	33	86.7	8.2	1.2	3.2	0.2	0.5	–

[1] Value is Saybolt Universal rather than Saybolt Furol

oil and gases, etc., obtained as products during a particular period come from the pasting oil as well as from the coal. Recycled oils form about two thirds of the feed and hence yields based on coal alone are necessarily rendered uncertain by the "netting out" calculation. In this latter differences between the product streams (heavy oil, light oil, and off-gases) and the feed pasting oil are taken as exclusively derived from the coal.

Operating conditions may be better compared, without the obscuring effect of netting out by evaluating plant behavior relative to total feed instead of coal feed. Two useful parameters based on total feed are organic insolubles remaining, and asphalt remaining, which are defined as:

$$\frac{\text{Organic insolubles in heavy oil, lbs.}}{\text{Organic insolubles in pasting oil, lbs.} + \text{m.a.f. (moisture and ash-free) coal, lbs.}}$$

$$\frac{\text{Asphalt in heavy oil, lbs.}}{\text{Asphalt in pasting oil, lbs.} + \text{m.a.f. coal, lbs.}}$$

M.a.f. coal is here regarded as being potentially either all organic insolubles or all asphalt. Per cent organic insolubles remaining is equal to 100 minus per cent liquefaction (conversion of benzene-insoluble material into benzene-soluble and water-soluble liquid substances and gases) of the total feed paste. The latter is not the same as per cent liquefaction of the coal, even at equilibrium recycle conditions when the vehicle has stable hydrogenation behavior from batch to batch.

Run B-3 was the first satisfactory one performed in the plant after it was moved to Bruceton from Pittsburgh and rebuilt. In tests 1 and 2 of this run, a fuel-oil operation on Rock Springs coal at 440° C. was performed using $SnS + CHI_3$ catalyst, in order to compare the behavior of the new plant with the earlier one at Pittsburgh. The Bruceton plant operated in a reasonably satisfactory manner and gave data which were consistent with earlier work. Operation under these mild hydrogenation conditions was found to be reasonably stable during 28 batches of test 1 and 17 batches in test 2. After some 400 hrs. of continuous operation, conditions were changed to start test 3, a fuel oil run at 460° C. converter temperature. This run was terminated after 96 hrs. of further operation.

Middle oil production in a simulated recycle operation with SnS catalyst promoted with NH_4Cl was tried in the first part of run B-4. In the latter part of this run metallic zinc was tested as a catalyst in a heavy or fuel oil operation.

Heavy or fuel and middle or light oil operations refer to conditions in which such materials constitute most of the plant product; to control this the hot catch pot temperature is low for heavy oil operation and relatively high in middle oil operation. In a commercial scale plant all the middle oil must be recovered; this is accomplished by maintaining the hot catch pot temperature high enough that the bottoms product of this trap is barely fluid enough for satisfactory handling. Condensable material recovered in the cold catch pot, or light oil trap, from the overhead of the hot catch pot, or heavy oil trap, is then distilled, and the distillation bottoms (generally +325° C. material) are added to the heavy oil trap bottoms to facilitate centrifugation and to make the quantity of centrifuge filtrate meet pasting oil requirements.

This apparently roundabout procedure is necessary because the heavy oil trap is not an efficient fractionator. Because it is desirable to separate *all* of the below, say, 325° C. material, the heavy

Table 3.- Average properties of middle oil produced in operation B-4.

Test	A.S.T.M. distillation, cumulative volume percent at: I.B.P. °C.	100°C.	200°C.	235°C.	300°C.	355°C.	E.P. °C.	Specific gravity	Proximate analysis, volume percent: Tar acids	Tar bases	Neutral oil: Saturates	Neutral oil: Aromatics	Olefins
1	68	5	17	28	59	81	392	0.960	13.8	2.7	7	62	31
2	64	4	19	30	54	76	384	.959	13.5	2.6	16	57	27
3	68	3	13	20	45	70	386	.974	11.6	3.7	13	53	34
4	71	3	13	21	46	70	393	.977	10.7	4.4	15	42	37

oil trap cut has to be made at about 400° C. with subsequent distillation of the overhead oils. However, insufficient light or middle oil is made in the present experimental plant to justify installation of a distillation step; overhead oils are merely sampled and stored. In tests 1 to 4 of run B-4, some 35% of the plant middle oil make was +325° C. material which, to simulate normal commercial operation more closely, should have been separated and added to the heavy oil to meet pasting oil requirements. Adequate sampling of heavy and pasting oil as well as tank and line drainage losses, which are disproportionately large for small plants compared with industrial ones, consume additional potential recycle oil. Consequently, in the middle oil tests of operation B-4 where the heavy oil trap was held at 400° C., make-up pasting oil had to be added to the centrifuge filtrate to supply enough oil for pasting. The make-up oil requirement depends on the plant throughput, and in these tests was 9.3, 12.4, 43.9, and 46%, respectively, of the total pasting oil used. This make-up oil was derived from previous cycles with the same catalyst (SnS promoted with CHI_3) at low heavy oil trap temperature; hence, the middle oil tests reasonably simulated large scale recycle operation.

The operation B-4 middle oil tests were each continued for eight batches; this is not quite long enough to be certain that all conditions dependent on recycle oil properties have stabilized at their equilibrium values. However, the various yields reported (except for asphalt and insolubles) are representative of this ultimate condition. Average properties of the middle oils produced are reported in Table 3. Slight trends in these data are probably not significant, and the material produced in all of these tests may be regarded as acceptably uniform.

After three middle oil tests at 460° C. and different pumping rates were completed, two intermediate flushing periods (tests 4 and 5) totaling 150 hrs. were provided in an attempt to clear the plant of SnS catalyst prior to testing metallic powdered zinc. In test 4 the SnS purge was tried while a middle oil operation was continued. Under these circumstances, although small quantities of tin catalyst may leave the system via the middle oil product stream and perhaps with the offgases, most of the tin remains in the heavy oil. In a middle oil operation all the centrifuged heavy oil is returned for pasting, and the centrifuge residue is the only stream in which tin can leave the circuit. However the tin concentration in both streams leaving the centrifuge (e.g., filtrate and residue) is about the same as it is in the original heavy oil; hence, within the limits of analytical uncertainty, tin is not selectively removed here. The tin purging rate is then primarily dependent on the weight ratio of centrifuge residue to centrifuge feed, which in this test averaged 0.3 lbs./lb. This, coupled with addition of make-up oils derived from earlier SnS catalyzed runs to supply pasting oil requirements, slowed down the tin purging rate effectively to zero. Although no additional catalyst was separately added during eight batches of test 4, the yields here are not significantly different from those obtained in test 3 with normal catalyst addition. To achieve an effective catalyst purge, the hot catch pot temperature was dropped, in test 5, to 200° C., thus increasing the physical volume of heavy oil and minimizing the sensibly tin-free light oil stream. In addition the paste rate was doubled, reducing the percentage loss of recycle oil as samples and mechanical handling. Under these conditions more centrifuged heavy oil is made than is required for pasting; thus, a better tin purge ratio exists around the centrifuge, and the need for make-up pasting oil is eliminated. These effects enabled the tin catalyst to be purged rapidly, and after four batches (i.e., 2 passes through the entire plant) liquefaction began to fall. The plant was deemed reasonably free of tin catalyst after 11 batches, at which time the viscosity and solids and asphalt content of the heavy and pasting oils had risen to such an extent that the plant was nearly inoperable. Powdered metallic zinc plus NH_4Cl was added to the feed paste in test 6, operation B-4, at the same 20 lbs./hr. pumping rate used in test 5. To maintain plant operability, it was then necessary (test 7) to cut back to a 10 lbs./hr. pumping rate. Nine attempts to obtain stable recycle operation with metallic zinc catalysts were made. Although really steady operating conditions were never long maintained using zinc catalyst, reasonably stable operation was achieved at the 10 lbs./hr. paste pumping rate but was unattainable at higher rates.

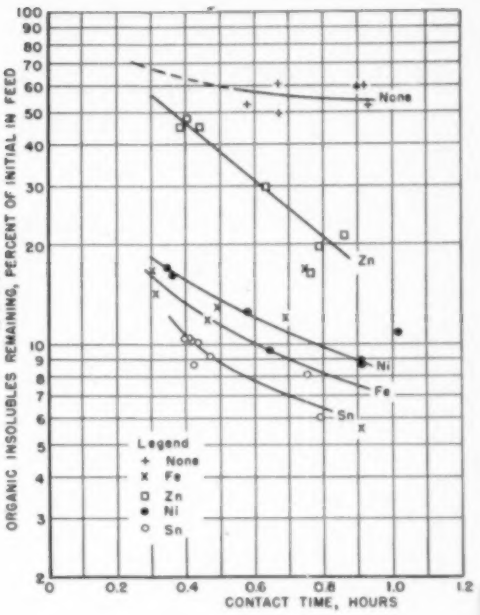

Fig. 1. Effect of catalyst on organic insolubles remaining; Rock Springs coal, 35% in paste, at 460° C. and 3500 lb./sq.in gage.

TABLE C.

Catalyst	Batch Autoclave	Pilot Plant 0.4 hr.	Pilot Plant 0.8 hr.
SnS + NH_4Cl	89	89	94
$FeSO_4$	85	87	92
$NiCl_2$	82	84	90
Zn + NH_4Cl	57	54	78
None	33	37	45

Because of difficulties experienced in purging SnS catalyst during operation B-4, it was decided to clean the entire plant mechanically during the shutdown following the run. This, together with replacement of tubing and pipe where necessary, effectively cleared the plant of catalyst traces from adherent deposits of previously handled materials. Operation B-5, using tin-free high temperature coke-oven tar as a vehicle, together with 35% coal, was then started. As was perhaps to be antici-

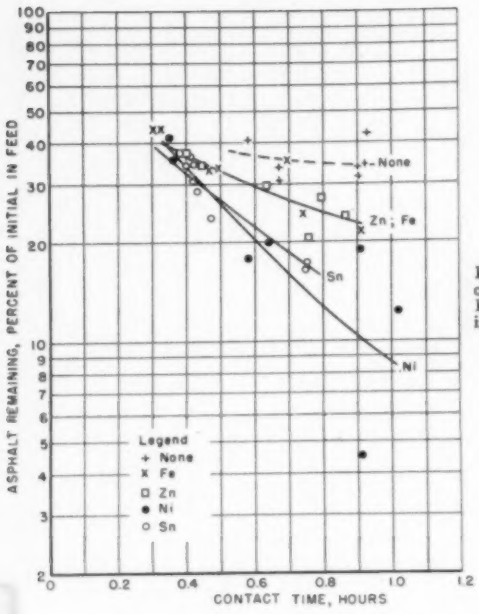

Fig. 2. Effect of catalyst on asphalt remaining; Rock Springs coal, 35% in paste, at 460° C. and 3500 lb./sq.in. gage.

pated, it was considerably difficult to run the plant with no added catalyst. Two tests were tried, however, at pumping rates of about 13 and 10 lbs. of paste/hr., and an approximate reference point established for the hydrogenation behavior of the test coal with no added catalyst. Hydrogen absorption, soluble oil yield, and hydrocarbon gas make are significantly smaller in the uncatalyzed tests than in the presence of an active catalyst at the same contact time and temperature.

The next run, B-7, was with $FeSO_4$ as catalyst added by an impregnation procedure; the treated coal contained approximately 1% Fe. Four tests were made at pumping rates of approximately 10, 16, 25, and 9 lbs. of paste/hr. The purpose of the last of these tests was to check the converter burden effect.

Operation B-8 was similar to B-7 but with coal which had been impregnated with aqueous $NiCl_2$ and which contained, after drying, approximately 0.5% Ni.

Although the yield data reported in Table 1 is quite indicative, unavoidable dispersion makes spot comparison of tabular data misleading and the several catalysts can best be evaluated by graphical comparison, as in Figures 1 and 2. The abscissa in both of these figures is estimated contact time, the ordinate being organic insolubles remaining or asphalt remaining. Although data for 440° C. are reported in Table 1 (for tests 1 and 2 of operation B-3) these values were not used in Figures 1 and 2, which are restricted to 460° C. data. The points shown on the figures are averaged points for 4 to 6 batch periods; several such periods are frequently included in a single test. At 460° C. and 3500 lbs./sq. in. gage, SnS gives the best conversion, with impregnated $NiCl_2$ and $FeSO_4$ almost as good (Fig. 1). Ni and Sn are practically equivalent in regard to asphalt breakdown and substantially better than Fe (*see* Fig. 2). Zn catalyst as used here is seen to be inferior to either standard non-impregnated tin or impregnated Ni and Fe catalysts. Conversions of 40-50% appear obtainable in the absence of any added catalyst.

Variation of yields with running time was particularly evident in the $FeSO_4$ run, and may be easily seen on Figure 1. In the first half (batches 1-4) of test 1, conversion was 83% at 0.74 hrs. contact time while in the latter half of the same test it improved to 88% at 0.69 hrs. contact. In test 2, although considerably shorter contact times (0.46 and 0.49 hrs.) were used, conversion was almost unchanged (87-88%). In test 3, the first four batches averaged 83% conversion in 0.3 hrs., while the last four batches averaged 86% at about the same contact time. The final test, while at somewhat longer contact than test 1, gives surprisingly good conversion, 94%. It appears reasonable to attribute these effects to variation in the converter burden with running time, and consequently the curves in Figures 1 and 2 indicate approximate trends; much longer steady operation will be required to establish limiting yields obtainable at equilibrium recycle for Ni and Fe impregnated catalysts. Even these comparatively short runs, however, show that these catalysts are nearly equivalent to tin in activity. Because comparison was made with what are effectively equilibrium recycle data for tin, impregnated Ni and Fe catalysts may be regarded as satisfactory substitutes for tin in liquid phase coal hydrogenation.

It is interesting to compare the results obtained with the several catalysts in these plant runs with those obtained under somewhat related conditions in batch autoclaves. The tabulation of % conversion in Table C is such a comparison.

The autoclave runs were made without added vehicle and with the same catalyst concentrations based on coal as in the plant; the method of addition of catalyst was likewise the same. They were all started with a *cold* hydrogen pressure of 1,000 lbs./sq. in. and were held at a reaction temperature of 450° C. for one hour. Correcting for reaction occurring during heating and cooling this is estimated as equivalent to 1.2 hrs. at 450° C., or 0.8 hr. at 460° C. The tabulated plant values were read from the smoothed curves of Figure 1 at 0.4- and 0.8-hr. contact time. The batch autoclave tests classify these catalysts in the same order as do the larger scale pilot plant tests, but at comparable time-temperature conditions (0.8 hr. at 460° C.) the pilot plant gives better conversion than the batch units. This may be due to the effect of recycling vehicle oils which contain residual active catalyst from a previous pass. Calculations, based on no preferential separation of catalysts by the centrifuge, show that the effective equilibrium catalyst concentration in the paste feed in a heavy oil operation is some four to five times as great due to recycle as would be calculated from the quantity added with the coal. Thus if catalyst concentration is an effective variable in these ranges, comparison between plant and autoclave data should be made at even shorter contact time. At 0.4 hr. (selected arbitrarily) the plant results are in excellent agreement with autoclave data. While it would be hardly justifiable to place too much emphasis on the degree of numerical agreement shown here, it is certainly safe to conclude that batch autoclaves provide an eminently satisfactory and relatively inexpensive method for accurately evaluating the potentialities of proposed catalysts.

(End of Part I)

PRACTICAL MIXING TECHNIQUES FOR VISCOUS MATERIALS

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This paper develops the fundamental mixing actions of low speed shear, wiping, smearing, folding, stretching and compression which are applicable to viscous materials. The dual purpose of the mixing elements is described and the difficulty of moving the entire mass of viscous material progressively into the active zone is emphasized. Combinations of equipment are suggested and the importance of proper physical preparation of the materials and the correct order of addition of the ingredients is explained.

MIXING is a fundamental operation in chemical engineering, whether it be to promote chemical interaction, scour through temporary association, or produce an end product of uniform analysis. Mixing may be defined as the manipulation of a heterogeneous mass of two or more materials so that an homogeneous product is produced which is uniform both as to analysis and structure. The size of the sample required to provide a repeated uniform analysis is a measure of the uniformity of the mix.

Valentine and MacLean (*2*) state, "The subject of mixing has been one of the most difficult of the unit operations of chemical engineering to submit to scientific analysis." This statement still holds and, if a search is made through the literature, a mass of disconnected papers is found covering the physical characteristics of various types of mixers, power requirements of and results obtained with individual mixers, and power requirements from theoretical considerations. Practically all these papers deal with paddle, propeller, turbine and ribbon mixers as used with fairly mobile liquids. Little information is available on the mixing of viscous materials. Failure to make a more detailed analysis of the mixing of viscous materials is no doubt due, in part, to the speed with which the practical mixing of plastics has developed and partly to the difficulty of differentiating between the power requirements of actual mixing and the power required to bring the viscous material into the active zone. It is likely realized now that progress here has been the result of compromise. It was necessary to use the small batch mixer of high horsepower and intensive action, and the continuous extruder of small cross section, or one must fall back on the lighter mixers of the Werner & Pfleiderer style (*1*), the roll mills or the muller-type mixers.

Mixing Actions Applicable to Viscous Materials. None of these machines mentioned employs the velocity or inertia action of the high speed rotary mixers. All use the fundamental mixing actions which may be applied to viscous materials. These are slow-speed shearing, smearing or wiping, folding, stretching and compressing. Most of the successful machines combine at least three of these fundamental actions.

Some elaborate machinery has been developed to perform these fundamental actions but the actual manipulation of the material itself is much the same as was the case in the crude hand-working of clay, the kneeding and rolling of dough, the hand-pulling of taffy, and the hand-mulling of pigments in oil. When a material is viscous, it can be extended by being drawn out by rotating arms, pressed out by rolls, extruded by screw or plunger pressure, or smeared and pressed out by muller wheels. The extended material may be folded on itself and again extended until the desired blend is obtained. In a modern mixer, the extension and folding occur once or twice per revolution and it should be noted that the multiplication of layers on a 2-4-8-16-32 basis is rapid.

However, the completeness of the mix can be seriously interfered with by two operating conditions. First, it is a fact that it is the toughest and most vicious ingedient of the mix which supplies the supporting struc-

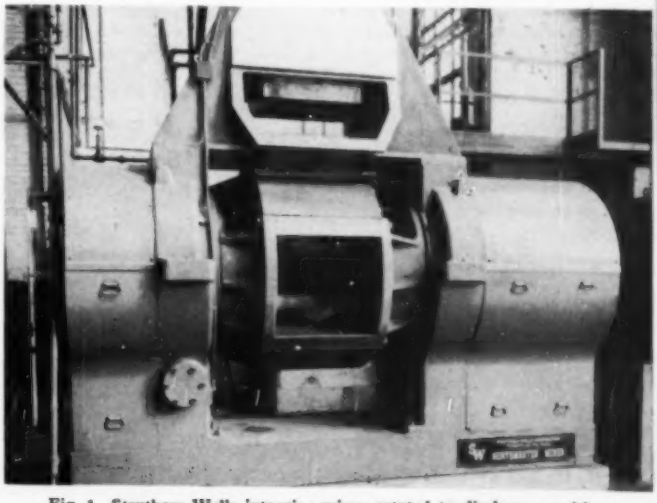

Fig. 1. Struthers Wells intensive mixer rotated to discharge position.

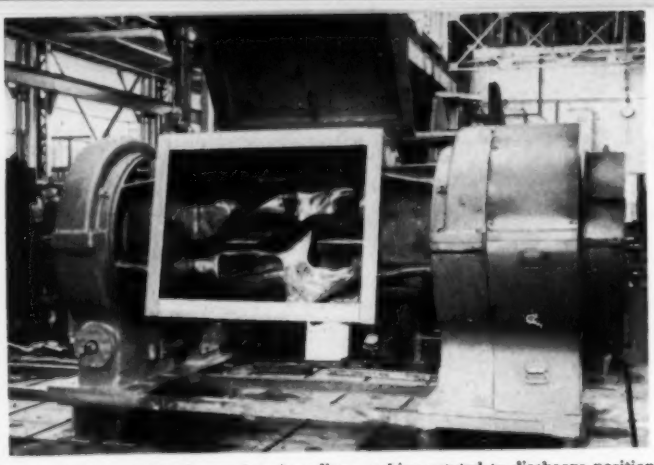

Fig. 2. Struthers Wells heavy duty kneading machine rotated to discharge position.

ture and which folds around the other ingredients as extension, folding and smearing progress. The more mobile materials are often locked up in touch envelopes of the more viscous material and the clearances of the mixer must be kept small if the envelopes are to be broken open and their contents distributed uniformly through the mass. Clearances must be close, not only between rotating members but also between the rotating members and the sides, ends, top and bottom of the mixer, as friction between the stationary and moving parts is an important factor in breaking down small pockets of material. This is the reason for the shaped cover on intensive mixers and its hydraulic closure.

Second, if the extensive exposure of surface, such as occurs in roll mills and in mixers fitted with light sigma or simplex blades, produces a surface drying or case-hardening, there is a tendency to form distinct strata which interferes with good blending. This action can be avoided sometimes by using slightly higher temperatures to produce a surface softness and tackiness or a small amount of softening solvent may be added to the mix.

Manipulation of Material Important. Correct manipulation of the material is as important as proper selection of equipment. The extreme range of action which may be produced on one type of equipment is illustrated by the method which was used to produce artificial ivory when cellulose nitrate was the prime plastic material. In producing artificial ivory stock, two batches of material, of different shades of white, were made up by mixing on two roll mills. When the mixing was completed, each batch was sheeted off the rolls to produce slabs of the same size and shape. The two slabs were then placed one on the other and passed between the rolls, which had been cooled to a point where the two pieces of stock were left strong enough to maintain their identity as separate layers of material. Passage through the rolls elongated the stock, reduced the thickness and combined the layers. With each pass through the rolls, the stock was folded on itself and, when the mass showed about 32 layers to the inch, a good imitation ivory was produced with practically no mixing of the lighter and darker shade materials. Here one had the same equipment either mixing or combining as the operator desired.

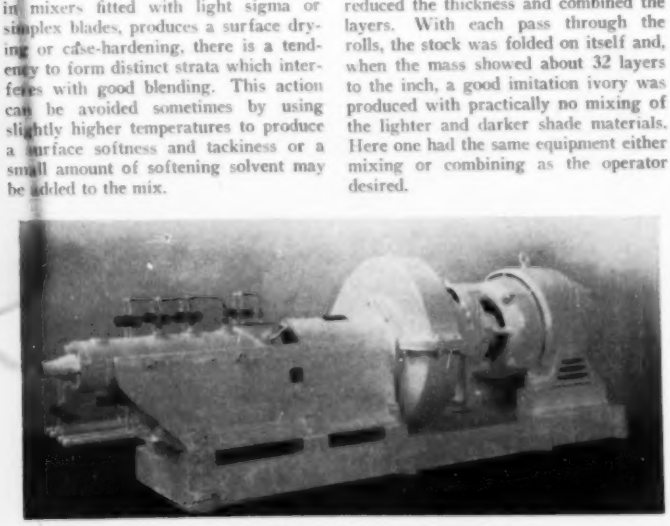

Fig. 3. Farrel Birmingham extruder mixer.

Mixer Construction. To be effective, mixers must fulfill four fundamental operating conditions: First, the mixer body must hold satisfactorily the materials of the mix; second, motion of the mixer or its blades must move the materials progressively into the active mixing zone; third, the primary arms or blades of the mixer must work on the materials in the active zone in a manner and with an intensity sufficient to produce the desired degree of mixing, and fourth, the mixer must empty itself quickly and cleanly.

When mixing nonviscous fluids, it is easy to design a mixer body in which the currents set up by the rotating elements will sweep the entire filled section and bring the material progressively to the point of greatest agitation and shear. Stationary baffles can be placed to direct the flow and the blade elements can be positioned relative to the sides and bottom of the chamber to give motion which avoids the settling out of materials of high specific gravity. Baffles or stationary mixing elements can also be placed to aid the shearing action of the moving elements. As materials become viscous, the flow becomes sluggish, parts of the mix not actually in the path of the moving elements are brought into the field of action more slowly and, in remote sections of the mixer, some material is likely to stick to the walls and never be brought into the zone of mixing.

Not only is the circulation of the material in the chamber unsatisfactory but also the efficiency of the ordinary paddles, propellers and turbine blades drops off rapidly as the viscosity increases. The blades do not readily shear through the mass, portions of the mass do not move off freely due to the impact or centrifugal action of the blades, and eventually the action degenerates to a rotation of a portion of the mass within the remainder, with a minimum amount of mixing at the zone of relative motion.

In handling viscous materials, it therefore becomes necessary to make special provisions for bringing the material into the active zone and to substitute other forms of mixing elements for the well-known high-speed rotating elements.

Types of Mixers Used on Viscous Materials. Various methods have been devised for insuring the presence of all the material in the active zone. In the Banbury mixer and other intensive mixers of the latest design, interlocking blades, a confined charge and small clearances are employed to produce intensive action throughout the batch. The cover is shaped to conform to the shape of the rotating blades and it is forced down on the charge by mechanical or hydraulic means. The charge is closely confined around the blades which are shaped and positioned through positive gear drives so that the whole mass of material is kneaded, sheared and smeared between the blades themselves and between the blades and the confining walls. The small clearances in these intensive mixers and the confining of the charge to the immediate vicinity of the blades limits them to small batches. Production is brought up to a reasonable figure by using high horsepower and rotating the masticating blades at the highest speed the material will stand. The friction produced in the confined space is great and with heat-sensitive materials the cooling problem is acute. Constant improvement is being made in the design of these intensive mixers along the line of controlled shear to use more of the power for useful work, but the combination of small batches, high power and short mixing cycle will always mean high temperature operation.

In the kneaders of the lighter Werner

& Pfleiderer type, the batches are larger and there is considerable space in the mixer body above the blades for the reception of material. Uniformity of mixing is achieved through the design of the chamber and the blades. The two mixing blades cover the entire bottom of the mixing chamber which is shaped to enclose closely their cylinders of rotation. Smooth vertical walls allow little purchase for the material to hang up above the blades and the operating level is kept so low that material does not come in contact with the domed cover. The blades are given different forms for various materials and they are so shaped that their rotation draws material down into the active zone. Relative positioning of the blades and suitable overlapping avoid build-up of sticky material on the blades. The clearances are relatively large in these kneaders so they cannot produce efficient fluxing and mixing of exceptionally tough materials.

Extruders have been used quite extensively during the past few years for mixing and blending plastics. The extruders used are of the screw type and the material is drawn into the feed worm from a supply hopper. In its passage down the barrel, the material is subject to shearing, rubbing and kneading and the direct work of the screw is supplemented by forcing the material through breaker screens and around breaker discs just before it is forced out through the nozzle. As the mixing zone is of small cross section and as the motion of the material is continuously in one direction from the inlet hopper to the nozzle, there is little large volume blending and the ingredients must be blended uniformly before being placed in the feed hopper.

The extruder will flux the mass and produce a uniform product from a uniform feed. Multiple-screw extruders produce an additional smearing and shearing of the material and a slight reverse motion which improves the blending action. Defects of extruder mixing evidence themselves as thin, hairline streaks, but, if the nozzle is a multiple one and the extruded material is being cut up into molding pellets, these thin lines are not serious.

Roll mills represent one of the oldest of the mixing devices which are suitable for viscous materials and they are our direct heritage from the rubber age. In roll mills, the supply of material is cradled between the rolls where it receives a kneading and folding action. A portion of the material is continuously drawn down between the rolls and, if the rolls rotate at different speeds, an added shearing and wiping action is produced. The rolls may be heated to soften the material to aid the mixing action or they may be cooled to protect delicate materials. A temperature differential between the rolls usually will cause the material coming down between them to stick to the hottest roll and follow it around back to the feed. This action produces a further blending and it allows the operator to cut through the mass on the roll, remove a lump of material and add it to the top of the supply at the nip of the rolls. These combined actions produce a blending of the entire mass and the milling time is selected so that all the material is subjected eventually to the same action. If extremely uniform blending is required, the rolls are set close together after a good mix has been produced and the entire batch is drawn through the rolls at tissue-paper thinness. The tissue is then bunched together, placed at the roll nip and, with the rolls set at the proper distance, it is collected on the take-off roll from which it is cut for delivery to the next operation.

Muller-type mixers can handle batches up to 50 cu.ft. in size and may be used either as preliminary mixers for fluxing mixers of the Banbury, extruder and roll types or, if the final mix is short and not too sticky, they can be arranged for crib and bedplate heating and used for the fluxing operation. Muller mixers were formerly restricted to putty-mixing and it has been only during the last few years that their extensive use in the chemical and food field has developed. They have a wide field of application as they can handle dry materials or wet materials over a wide range of viscosities. Extremely fluid mixes cannot be mulled as there is not sufficient friction to rotate the mullers and they swing round the turret as heavy, inefficient, slow-speed paddles. Viscous materials which are short in structure and which can be folded over by the plows are mixed efficiently but long, extremely sticky materials bunch up in front of the plows and do not fold over in front of the mullers.

In the muller-type mixers, the material rests in the pan and is either brought to the mixing elements by rotation of the pan or the muller wheels, ploughs and scrapers rotate around a central turret in the pan, through the mass of material. Stationary pan mullers are usually preferred where dust- and fume-tight enclosures must be used and where the discharge is linked to a conveyor system. The muller wheels squeeze the material and smear it on itself as they rotate, while the plows and scrapers fold the material on itself and return it to the path of the mullers with each rotation. Mixing of materials which fold freely is rapid as the layers double with each passage of the plows so that, theoretically, more than 260,000 layers are produced in one-half minute with the mixer rotating at 39 rev./min. The folding produced by the plows is not very uniform so that there is a breaking-down of the layers, which aids the mixing action.

Separate Mixing from Fluxing. The majority of chemical engineers are users rather than designers of equipment and, in their selection of equipment, they are restricted to what the machinery market has to offer. The machinery market, in its turn, is determined by early process developments and is set by mass trends. Thus the influence can be seen clearly of that first plastic material, natural rubber, on the equipment available today for mixing viscous materials. Except in the case of latex, which is a comparative late arrival on the scene, natural rubber was always in the form of a tough, viscous mass and the equipment which was developed to wash, blend and mix natural rubber was heavy and high powered. This rubber machinery was designed to heat-soften, tear, fold and smear a tough, viscous material and wrap it around the other ingredients of the mix. The body of the tough rubber had to be broken down by great force before the materials could be blended with it and the operations of mixing and fluxing were one and the same. Starting in the 1930's, use of plastic resins developed rapidly and it was natural to use modified rubber working machinery for their processing and to continue combining the operations of mixing and fluxing. However, now it is not often in the interests of economy or quality to combine these operations.

A large proportion of our plastic resins can be obtained in a free-flowing state for compounding and the extremely viscous plastic state need not be developed until the last fabricating operation is undertaken or until the material is prepared as a feed for this operation. Therefore, it is good practice to prepare the intimate mix of free-flowing materials in lighter auxiliary equipment and reserve heavy-duty Banbury or intensive mixers and extruders for the final fluxing operation. This procedure should pay dividends in lower power costs,

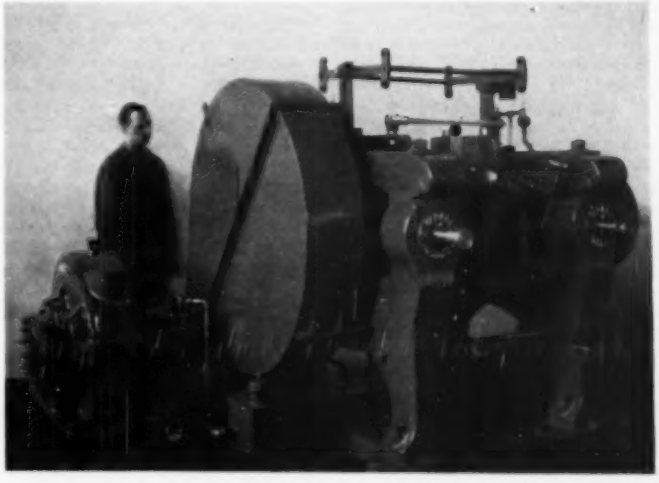

Fig. 4. Farrel Birmingham heavy duty roller mill.

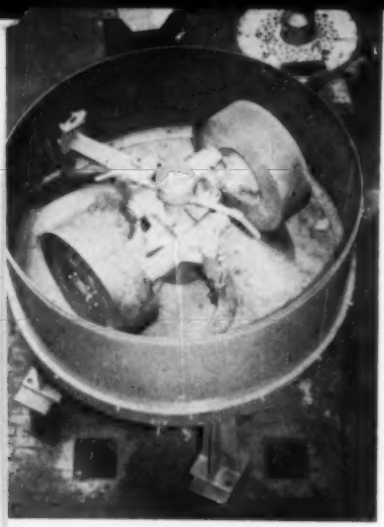

Fig. 5. Simpson mix muller. View into mixing pan showing mullers, liquid addition funnel and plows.

greater production from expensive heavy-duty equipment, better quality of mix and lessened chance for heat damage to the material.

For instance, if a mixer of Banbury type is being used to mix and flux a mixture of powdered resin, fillers, pigments, lubricants and plasticizers, the ingredients should be mixed in lighter equipment and fed to the Banbury for the fluxing operation only. Operating in this manner cuts down materially on the heavy mixer cycle and allows more production from this expensive equipment. Also, it often leads to the production of a better product. This is especially true where one or more ingredients of the mix are present in small amount. When fluxing starts in heavy-duty mixers, the flow becomes sluggish, materials present in small amount become encased in other materials, intimate mixing is more difficult and more time is required for perfect blending. If the materials are blended while still free-flowing, the intensive mixer is relieved of this duty. Also, it will often be found that where the heavy-duty mixer is required only to flux a uniform mix of material, further power and time can be saved by preheating the mix in the lighter equipment to a temperature just under the softening point. Heat from direct combustion is much cheaper than frictional heat, even where the frictional heat seems to appear as a necessary product of work done on the material.

The graduated use of equipment produces some interesting combinations of apparatus and it should be noted that the final result of superior uniformity of mix is even better than the simple sum of the mixing and fluxing actions. This is due to the fact that each separate step with these materials is a batch operation and considered as a separate load, each batch is subject to the faults of batch production such as incorrect weighing, low or high temperature, small variations in processing time, etc. In going from one machine to another of different type, there is a chance for some of these irregularities to be ironed out.

An interesting combination of mixing and fluxing equipment is furnished by the tandem use of the Simpson muller mixer, Banbury mixer, two roll mills and connecting conveyor system to feed plastic compound continuously to large five-roll calenders. When a 78-in. five-roll calender is producing 20-point sheeting (.020 in.), it requires a lot of plastic to keep it going. The powdered plastic resin is dropped into the Simpson mixer where it is combined with fillers, pigment, lubricant and plasticizer. The discharge from the Simpson mixer can be dry and free flowing, slightly moist and tacky or lumpy due to slight preheating. This pre-mix is dropped into a Banbury mixer and fluxed to a soft, lumpy mass. This mass is conveyed to the two roll mills where the mass is sheeted out, the sheets cut into strips and bundled up to form a feed for the calender. The combination of three mixing actions produces a uniform product which can be flattened and extended into a continuous sheet of uniform color and texture on the calender. Careful conveying between operations conserves the heat in the material, avoids surface drying and insures cleanliness.

Preparation and Addition of Materials. In order to insure the greatest production of high grade material from both light- and heavy-duty mixers, it is important that the physical preparation of the material be correct and that the ingredients be added in their proper order. The ingredients of the batch must be examined carefully. Some finely powdered ingredients, such as carbon black, contain a great amount of air and, if possible, should be compacted or wet-out before being added to the mix. If any light solvent is a part of the formula and if it is present in sufficient quantity, it may be used to wet down the fine powder and drive out the air. If the powder cannot be wet down, it may be possible to densify it somewhat by mixing it with other dry ingredients in a muller-type mixer.

Ingredients such as vulcanizers, anti-oxidants and anti-acids are usually present in small amounts. Most of these substances have a tendency to form aggregates and, before addition to the mix, they should be fluffed either by screening or by passage through a small hammer mill. Time of mixing is cut down and the uniformity of the product will be improved if all ingredients are freed from aggregates before being added to the mix. Soft aggregates may be broken down by a screening operation which can be combined with a scalping operation to remove foreign matter, such as pieces of bag, wood splinters, etc. Hard aggregates require the action of a hammer mill, but there is a wide range of aggregates which can be broken down in a muller-type mixer as part of a preliminary mix of dry ingredients, if the material containing the aggregates is placed in the muller and processed for a minute or two before adding the other ingredients, which might produce a cushioning effect. If any of the solid materials which are present in small amounts are soluble in any liquid portion of the mix, it is well to add them to the mix in liquid form, making provision, of course, to distribute the liquid uniformly over the surface of the mix. Where a trace of material is to be added and it is not soluble in any other ingredient of the mix, it is sometimes necessary to add it as a dilute solution of a neutral solvent, with provision to evaporate the solvent at the end of the mixing cycle.

In closing it should be stated that there is a common ingredient of all mixes which seems to require a little more consideration in the case of viscous mixes. This ingredient is *time*. It takes a little more time to blend sluggish, tacky materials than to mix free-flowing substances and, if there is any chemical interaction in the mixture, the time for the interaction must be added to the time necessary to make the basic, uniform mix because some of the chemicals do not start reacting until the last particles are brought into contact. Thus plenty of time is a desideratum in viscous mixes. Other ingredients should be selected with care especially as regards their physical state and condition, as well as their purity. They should be combined in a manner which avoids clotting and lumping. Operations should be scheduled so that all possible blending and mixing are done with free-flowing materials in light equipment under carefully controlled conditions and the final fluxing done in a minimum of time in heavy, high-powered equipment.

Literature Cited

1. Freyburger, Paul, U. S. Patent 180,568 (1876).
2. Perry, J. H., "Chemical Engineers' Handbook," 3rd ed. McGraw-Hill Book Co., New York, N. Y., 1195 (1950).

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FLUID CATALYST-GAS MIXING IN COMMERCIAL EQUIPMENT

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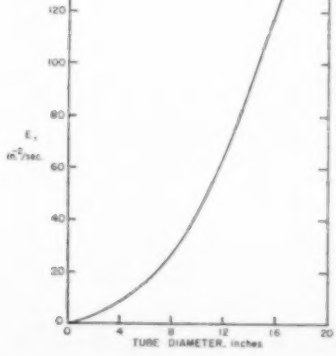
Gas samples have been withdrawn from various points in the fluid catalyst bed of a 40-ft. diameter commercial catalytic cracking regenerator. Composition data indicate that a high degree of gas down-mixing exists, since essentially no variation in gas composition was found at any point. It also seems probable that most of the gas introduced passes through the bed in the form of bubbles, rather than flowing around and fluidizing the catalyst particles. Thus a fluid bed with a small length to diameter ratio may be an inefficient reactor as far as vapor-solid contacting is concerned. Also the degree of gas down-mixing which exists may make such a system insufficient for carrying out reactions where a high conversion is desired, or where the products formed inhibit the reactions.

SINCE the advent of catalytic cracking as a refining process, considerable interest has developed in the behavior of reacting systems in which a fluidized bed of powder is maintained, and much work has been carried out on the properties of such a bed. It has been shown that the rate of circulation of the solid is quite high, and also that there is considerable "carrydown" of gas from the top of the bed, the gas mixing with that entering the bed. The amount of such carrydown has been shown to follow the laws of eddy diffusion (*1*) but with constants of such magnitude in small diameter tubes that the amount of mixing is not very great. However, experiments carried out in the Houston research laboratory have shown that as the diameter of the tube containing a fluid bed is increased, the eddy diffusion constant becomes large, and the composition of the gas throughout the bed approaches uniformity. These results are plotted in Figure 1, from which it can be seen that although in small diameter tubes the amount of down-mixing may not be significant, in large diameter vessels where the L/D ratio is low, mixing will probably be nearly complete. If a reaction is taking place in a completely mixed fluid bed, the effective concentration of the reactants in the reaction zone is that which exists in the exit stream from the bed, and is much lower than in a nonmixed bed under the same conditions. Thus if gas mixing occurs to a large extent in commercial fluid bed catalyst reactors, this mixing should have an adverse effect on reaction rate (*1*).

A commercial catalytic cracking unit provides an example of a large diameter fluid bed. In the case of the regenerator the gases to be sampled are relatively stable and readily analyzed with conventional equipment. To investigate the degree of mixing which occurs in commercial equipment, a series of samples has been withdrawn from the regenerator of the catalytic cracking unit of the Shell Oil Co. Houston refinery. Results are presented in this paper.

Experimental. The regenerator of the catalytic cracking unit is a 40-ft. diameter vessel containing normally a 15-ft. bed of catalyst above the grid. The grid, designed to accomplish air distribution, consists of heavy parallel beams located on 24-in. centers with a 2-in. clearance between them. Small spacing strips 10 in. long are welded parallel to the axis of the beams on 16-in. centers leaving 2 in. × 6 in. rectangular openings for passage of gas and catalyst. The calculated pressure drop through this grid is about 0.5 lb./sq.in. The spent catalyst riser in the cone of the regenerator ends in a spider distributor to improve air distribution. Catalyst is withdrawn from the bed in two standpipes, transferred with air through water-cooled tubes in two catalyst coolers, and returned to the vessel below the grid.

To obtain gas samples from various points in the catalyst bed in this vessel, permanent gas-sampling facilities have been installed. In order that the samples have significance, no reaction may occur in the gas after it has been withdrawn from the bed. Since a sample from the center of the regenerator must travel 20 ft. through a bed of catalyst at a high temperature, further reaction of the oxygen in the gas with either coke on the catalyst or carbon monoxide in the gas could easily take place. To avoid these reactions, catalyst must be eliminated from the sample and the gas temperature lowered at the point of sampling. The samplers were designed with a filter at the point of sampling to remove catalyst, and a jacketed exit tube, to cool the gas being withdrawn.



◄ **Fig 1. Effect of tube diameter on eddy diffusion constant (*1*).**

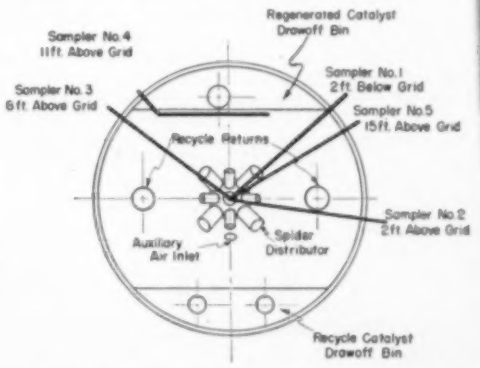

Regenerated Catalyst Drawoff Bin
Sampler No.4 11ft. Above Grid
Sampler No.1 2ft. Below Grid
Sampler No.3 6ft. Above Grid
Sampler No.5 15ft. Above Grid
Recycle Returns
Sampler No.2 2ft. Above Grid
Auxiliary Air Inlet
Spider Distributor
Recycle Catalyst Drawoff Bin

Fig. 2. Gas sampler locations commercial regenerator. ►

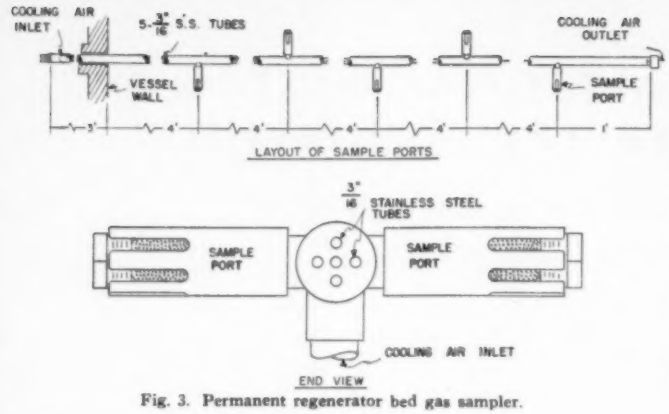


Fig. 3. Permanent regenerator bed gas sampler.

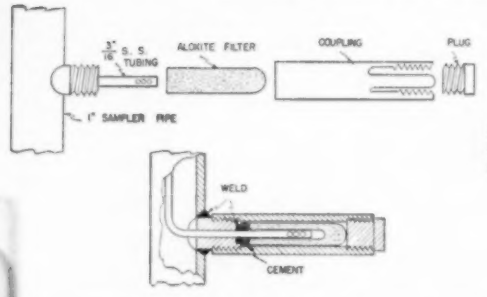


Fig. 4. Filter and protective housing for regenerator bed gas sampler.

Location and construction of the samplers installed above the grid in the regenerator are shown in Figures 2 and 3. Each of the four samplers consists of a 24-ft. section of 1-in. schedule 80 chrome-moly pipe having five Aloxite filters in protective housings welded on perpendicularly at 4-ft. spacings. A separate 3/16-in. stainless steel tube receives the gas from each filter and returns through the 1-in. pipe to the sample take-off. The pipe jacket containing the individual tubing lines passes out of the regenerator through a nozzle on the vessel. A continuous bleed of air regulated by a restriction orifice is passed through the jacket as a cooling medium for the regenerator gases. The sampler located 2 ft. below the grid in the cone is identical in construction with those above the grid except that it is equipped with four filter assemblies in place of five. The samplers 2 ft. below, 2 ft. above, 8 ft. above, and 15 ft. above the grid all extend to the center of the vessel, having a sample point in the center and at 4 ft. intervals radially outward. The sampler located 11 ft. above the grid is bent to follow above the baffle for the regenerated catalyst draw-off bin. The top of this baffle extends 3 ft. above the grid.

Figure 4 is a diagram of the protective housing for the filter section of a sampler. The filter is constructed of Aloxite of 5 permeability (5 cu.ft./min.)/(sq.ft.)/(2 in. of water pressure) drilled, counter-sunk, and cemented to the sampler pipe end over the perforated 3/16-in. stainless steel tubing. The filter housing consists of two ½-in. 3000-lb. chrome-moly couplings welded together. One end is attached to a male fitting made from bar stock. Six ¼-in. equally spaced slots are cut in the other end which is fitted with a ½-in. plug. Several earlier samplers failed because the filter broke or came off the mounting. The present arrangement has given the necessary protection to the filter to withstand the thermal shock and severe agitation to which it is subjected in the bed and yet provides sufficient exposure of the filter to the regenerator bed gas to obtain gas rates as high as 50 cc./sec.

Gas reactions on the surface of the sampling filters were discounted because the turbulent action within the fluid bed would cause a "scrubbing" action of particles flowing past the filter; this effect would prevent accumulation of any significant layer of particles on the filter surface. The quantity of particles trapped within the porous structure of the filter would appear to be limited, and the carbon on such particles would be burned off within a short time so that only the initial gas withdrawn might be affected.

The superficial velocity of the regenerator during the sampling period averaged about 1.55 ft./sec. A typical particle-size distribution of the catalyst in the regenerator is given in Table A.

TABLE A.

Particle Size, micron	% wt.
0–40	7.5
40–60	24.5
60–80	24.0
80–100	18.0
100+	26.0

Gas samples were withdrawn slowly (over a 5-10 min. interval) from each sample point and collected in rubber balloons, in glass bombs over magnesium sulfate brine, or directly into a portable Orsat apparatus and analyzed immediately. All sample handling methods gave the same results. The Orsat analyses were checked in several cases by mass spectrometer tests. In all cases satisfactory accuracy (±0.2%) was obtained. Experiments in which samples were withdrawn rapidly showed appreciable variations in gas composition for reasons which will be discussed later.

Results and Comment

Three vertical concentration profiles taken at the center of the bed are shown in Table 1. One of these is plotted in

TABLE 1.

Vertical Gas Concentration Profiles from Center of Regenerator

Sample Location Run		Gas Composition Mol % CO_2	CO	O_2	N_2	CO_2/CO	Mols O_2 Unaccounted For Per 100 Mols of Inlet Air
2' Below Grid	1	9.1	6.7	1.4	82.8	1.36	7.7
	2	9.2	7.4	1.4	82.0	1.24	7.2
	3	9.6	7.1	1.6	81.7	1.35	6.8
2' Above Grid	1	13.7	8.7	0.4	78.2	1.46	3.5
	2	15.9	9.4	0.1	76.6	1.48	1.8
	3	14.1	9.6	0.1	76.2	1.47	1.3
8' Above Grid	1	12.2	9.0	0.2	78.6	1.36	4.6
	2	15.0	8.8	0.0	76.2	1.48	3.4
	3	12.8	8.5	0.4	78.3	1.50	3.5
11' Above Grid*	1	10.8	8.8	0.2	80.2	1.23	5.8
	2	12.0	8.7	0.1	79.2	1.38	4.6
	3	12.0	9.1	0.3	78.6	1.32	4.0
15' Above Grid	1	11.0	8.4	0.2	80.4	1.31	5.9
	2	11.6	9.2	0.0	79.2	1.26	4.9
	3	12.2	8.3	0.2	79.3	1.47	4.3
Stack	1	10.6	8.5	0.9	80.0	1.25	5.4
	2	10.7	8.8	1.5	79.2	1.22	4.6
	3	11.0	8.5	1.1	79.4	1.30	4.7

*Radial penetration, 4' from vessel wall.

Bed height = 15'.

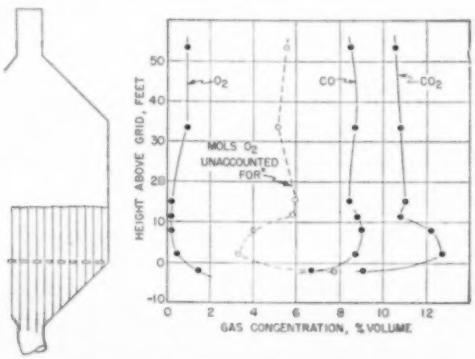


Fig. 5. Vertical gas concentration profile of regenerator. * Same numerical scale as gas concentration.

Figure 5. Radial gas profiles at four levels are included in Table 2 and Figure 6 is a graphical presentation of one such set of data for oxygen. All samples in any given set essentially were taken simultaneously over a 5-15 min. interval while the regenerator was operating at constant conditions. Agreement among the various sets of data is good, and as mentioned previously, the accuracy of the analytical methods used was satisfactory. Data show that the measured composition of the gas at all points in the bed is approximately the same, and that especially the oxygen content is quite uniform and low. Thus a considerable degree of mixing is indicated. The rapidity of this mixing is illustrated by the fact that the radial sample traverse taken 2 ft. below the grid shows no effect from the introduction of high oxygen content recycle gas in the cone of the regenerator.

Several abnormalities are readily apparent in these data, however. The oxygen content of the flue gas is higher than that measured for any gas above the regenerator grid. Obviously it is impossible for more oxygen to be in the stack gases than in the catalyst bed, unless a gas stream richer in O_2 than that in the bed passes through it without being measured. Channeling of the inlet gases through a portion of the bed not covered by a sampler might account for this, but since the vessel is symmetric, and more than half the cross section contains samplers, this seems improbable.

A study of the behavior of fluidized catalyst in small tubes leads to an obvious explanation. It has been frequently noted (*2, 3*) that when gas velocity through a fluid catalyst bed is increased beyond a certain point, "bubbles" form, and a portion of the gas passes through the bed in this manner. The rate of movement of the bubble through the bed is primarily a function of bed density and bubble size, and not gas velocity. The volumetric rate of gas flow past the sample point is far greater while a bubble is passing than when the sample point is surrounded by fluidized catalyst. Consequently, withdrawing gas at a constant rate will collect a nonrepresentative sample by collecting less gas from bubbles than their rate of flow warrants.

A further verification of this postulation is provided by the results of samples withdrawn as rapidly as possible (in about 10 sec. each). If a sample is withdrawn during a sufficiently short interval, an occasional sample should consist largely of gas passing the sample point as a bubble, and should show an oxygen content higher than that in the stack gases. Rapid sampling data shown in Table 3 indicate that this is the case. The magnitude of the fluctuation shown in these data is consistent with the conclusion that an appreciable fraction of the total gas passes through the well-mixed regenerator bed in the form of bubbles.

TABLE 2

Radial Gas Concentration Profiles at Various Elevations in Regenerator

Penetration in Vessel	CO_2				CO				O_2				N_2			
	6	10	14	18	6	10	14	18	6	10	14	18	6	10	14	18
2' Below Grid		9.0	7.8	9.6	10.0		8.6	7.0	7.9	7.0		0.4	2.6	1.0	1.5		81.2	80.4	81.5	81.7
Penetration in Vessel	4	8	12	16	20	4	8	12	16	20	4	8	12	16	20	4	8	12	16	20
2' Above Grid	15.4	14.0	14.4	14.0	14.6	10.1	9.9	9.8	9.0	9.6	0.3	0.4	0.2	0.6	0.2	74.2	75.7	75.6	76.4	75.6
8' Above Grid	10.4	10.6	11.6	11.6	11.6	9.2	9.2	9.2	8.5	0.6	0.6	0.4	0.6	0.5	79.8	79.6	78.8	78.6	78.2	
11' Above Grid	10.1	11.4	11.4	11.5	11.7	8.9	9.1	9.0	9.2	9.0	0.5	0.3	0.4	0.5	0.5	80.5	79.2	79.2	79.2	79.0
Stack			10.6					8.2				1.8						79.4		

TABLE 3

"Rapid" Sampling 11' Above Grid Near Wall

Percent Oxygen in Series of Rapid Samples
0.1; 1.0; 0.7; 0.3; 0.0; 0.1; 0.0; 3.1

Percent Oxygen in Stack During Above Sampling
1.0

Samples taken over 10 sec. intervals.

In the gas in the interstices of the bed must have an oxygen concentration approaching zero since the average of this material and that passing in bubbles is very low. This indicates either that the rate of combustion of coke on the catalyst is quite high when oxygen can reach the surface or that the gas in the interstices circulates throughout the bed but is not replenished rapidly. Neither of these explanations was expected from previous work.

Data in Table 1 also show that the moles of oxygen unaccounted for apparently go through a minimum at a point 2 ft. above the regenerator grid. For this to occur, a gas containing oxygen but not nitrogen must be released at this point. No completely satisfactory explanation of this phenomenon is available. An oxidation-reduction cycle of iron on the catalyst has been proposed in which the iron is oxidized near the top of the bed and reduced near the grid, but no reason for the existence of such a cycle can be given. Experimental verification of this cycle would be difficult, since the rate of movement of catalyst in the bed is so great that an infinitesimal change in oxidation level of the iron contaminant could account for the observed result.

A more probable explanation of this phenomenon lies in the adsorption of carbon dioxide on the catalyst. Work here has shown that at room temperature cracking catalyst preferably adsorbs CO_2 over O_2, or N_2. Water vapor is even more strongly adsorbed. If these results can be extrapolated to 1050° F., the gas adsorbed on the catalyst at the top of the bed would be relatively rich in CO_2 and H_2O and low in O_2 and N_2. Samples of gas and catalyst withdrawn from the spent catalyst riser (Table 4) indicate that the hydrogen in the coke is burned at a more rapid rate than is the carbon, and consequently the ratio of H_2O to CO_2 should be greater in the gas below the grid in the regenerator than it is in the bed. Thus it seems possible that when catalyst which is in equilibrium with stack gas of a relatively low H_2O/CO_2 ratio is brought in contact with a gas (issuing through the grid) where the ratio is higher, a small amount of CO_2 might be desorbed and released. Since the catalyst circulation rate due to turbulence within the bed is high, even a small amount of CO_2 released per pound of catalyst could affect the gas composition appreciably. An indication of the validity of this explanation is furnished by the fact that where the moles of oxygen unaccounted for are low, the CO_2/CO ratio in the gas is also high (Table 1). This mechanism is possible only if gas mixing is incomplete at the grid which might well be caused by jetting action through the grid.

The principal conclusions which can be drawn from these data are as follows: (1) In large diameter fluid catalyst beds, the degree of catalyst-gas down-mixing is great since the measured composition of the gas in catalyst interstices throughout the bed is nearly constant. If mixing were not extensive, the gas in the interstices at the bottom of the bed would have a higher oxygen concentration than that at the top, since its residence time would be short. (*2*)

TABLE 4

Riser Sampling

	% W. C	C/H Mol Ratio
Spent Catalyst	2.60	1.44
Catalyst ex Regenerator Riser	1.30	2.00

	CO_2	CO	O_2	N_2	H_2O	H_2O/CO
Gas ex Riser	2.0	1.5	13.0	75.2	8.5	4.8
Gas ex Stack	9.0	6.5	2.7	73.2	6.8	1.0

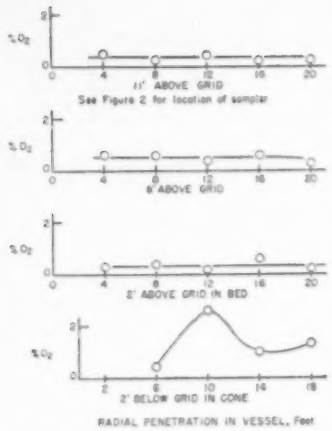

% O2
11' ABOVE GRID
See Figure 2 for location of sampler
8' ABOVE GRID
2' ABOVE GRID IN BED
2' BELOW GRID IN CONE
RADIAL PENETRATION IN VESSEL, Feet

Fig. 6. Radial O_2 profiles in regenerator at various elevations.

A considerable portion of the gas passing through a fluid bed does so in the form of bubbles which may have a relatively low residence time in the bed and does not reach the same composition as the gas in the interstices. (3) The high CO_2 concentration at the bottom of the bed may be caused by displacement of adsorbed CO_2 from the catalyst by steam.

These phenomena have a large effect on the rate of a reaction taking place in a fluid bed. Obviously, in a completely mixed bed, the average partial pressure of the reactants is equal to their partial pressure in the exit stream rather than to some average of inlet and outlet partial pressure, and, other conditions being equal, the reaction rate will be reduced. Therefore, in a completely mixed catalyst bed, the contact time required to obtain a given conversion in a reaction will be higher than would be necessary if the reaction were carried out in the absence of mixing. The extent of this contact time increase for various reaction kinetics is shown in Figure 7. For all cases, the disadvantageous effects of mixing become more pronounced as conversion approaches the thermodynamic equilibrium. A reaction in which the products have an inhibiting effect is particularly sensitive to the effects of mixing. In this case (first-order reaction, first-order inhibition by products), it can be seen that even at low conversions, a nonmixed reactor can operate at twice the space velocity of a mixed one. For the more common case of a first-order uninhibited reaction, the effect becomes pronounced only when conversions in excess of 50% are attained, and is greater for reactions in which a large volume expansion occurs. Since it is usually desirable to operate a commercial reactor at as high a conversion as possible, the effects of mixing on increasing severity requirements will ordinarily be pronounced (*1*). Also the longer contact time may increase the extent of undesirable side reactions.

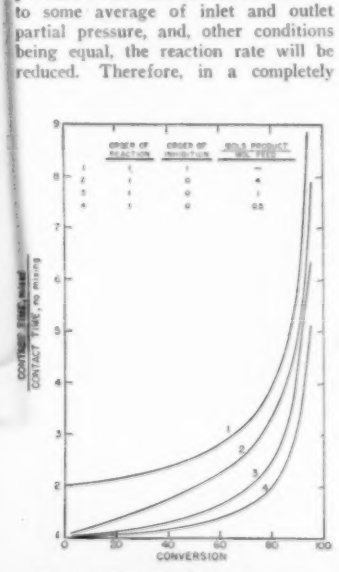


Fig. 7. Effect of mixing on reaction rates.

The occurrence of bubbles in a fluidized catalyst bed further affects the severity requirements for a reaction by reducing the efficiency of contacting of the catalyst particles and the reacting gases. The gas which passes through the bed in the form of bubbles comes in contact only with the catalyst on the surface and that which "rains" down through the bubbles (*3*), and thus contacting is not so intimate as that which occurs in the interstices of the bed. The fact that some contacting of gas and solid occurs in a bubble is demonstrated by the fact that it is possible to operate the regenerator of a commercial catalytic cracking unit down to essentially 0% oxygen in the stack gases. This can be accomplished by increasing the bed level, but would be impossible if the bubbles represented a true by-passing of the entire bed. The bubbles, since they do not give as effective contact between catalyst and gas, cause a lowering of the reaction rate for the material in the bubbles. The extent of reaction under these circumstances is less than it would have been if all the gas were passed through at the same contacting efficiency, and thus bubble formation further increases the contact time required to obtain a given conversion above that required in a completely mixed, nonbubbling bed. It should be remembered, however, that the presence of bubbles may be required for good heat transfer because of the high degree of turbulence imparted to the bed.

The rate of "rain" of catalyst through a bubble probably is nearly constant, so that as the residence time of a bubble in the bed is increased, its contents come in contact with an increasing amount of catalyst and the extent to which they will react will increase. The rate of movement of a bubble, however, is not primarily a function of gas rate. Its residence time may be increased by increasing the volume of the bed, which can be accomplished by reducing the bed density. Since the physical properties of catalyst particles influence the bed density and the quality of fluidization, these properties may have a pronounced effect on the apparent specific activity per unit weight of a catalyst. For example, if two catalysts show the same specific activity when used in a fixed bed, the one which fluidizes to the bed of lower density containing fewer large bubbles will show the higher specific activity in fluid application. A catalyst with smooth particles, since it presents less resistance to flow through the interstices, will permit a higher superficial gas velocity before large bubbles form. In general, a catalyst with a small average particle size but fairly wide particle-size distribution will give a less dense bed than a coarse material. Electrical and magnetic effects, as well as moisture content, affect the "stickiness" of a powder, and influence the behavior of a fluidized bed. A sticky catalyst, one with a high fines content, or one with a narrow particle-size range without fines tends to give beds which fluidize poorly and contain excessive bubbles.

Since the volume of a fluid bed probably governs the average residence time of bubbles within it (other conditions being equal), the volume hourly space velocity should be of more significance when bubbles occur than the corresponding weight unit. For carrying out certain reactions, particularly where a high conversion is desired, or the products formed inhibit the reaction, a large diameter fluid bed may be an inefficient type of reactor, and it may be desirable to introduce into the bed certain baffles or redistributors, such as grids, to reduce the amount of gas down-mixing and to break up and reform bubbles, thus improving the contacting efficiency of gas and solid.

Literature Cited

1. Gilliland, E. R., and Mason, E. A., *Ind. Eng. Chem.*, **41**, 1191 (1949).
2. Matheson, G. L., Herbst, W. A., and Holt, P. H., 2nd, *Ind. Eng. Chem.*, **41**, 1099 (1949).
3. Morse, Rollin D., *Ind. Eng. Chem.*, **41**, 1117 (1949).

(*Presented at Boston Meeting, Swampscott, Mass.*)

DIFFUSION RATES IN EXTRACTION OF POROUS SOLIDS

1. *SINGLE PHASE EXTRACTIONS*

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Knowledge of liquid diffusion rates in porous solids has applications in solid-liquid extraction and in catalysis. Aqueous solutions of potassium chloride, sodium chloride, potassium chromate, copper sulfate, and acetic acid were extracted from three types of carrier solids of increasing complexity: single capillaries, tubes containing beds of small glass beads and porous alumina spheres. The transfer mechanism was verified as being diffusional. Equations were derived for the extraction of a single phase solute from spheres in the case of batchwise, counter-current, and parallel operation. Validity of the equation for batchwise operation was verified by extractions from porous alumina spheres under several conditions of concentration, solvent volume, and temperature.

The concept of a pore shape factor, K^2, is introduced. This is equal to the ratio of the actual to the theoretical extraction time, or for an actual sphere of measured radius R, an equivalent, idealized sphere of radius KR, can be postulated, whose structure offers no resistance to diffusion. This factor is used in interpreting and correlating the extraction data.

IN the extraction of soluble materials from solids and in catalytic operations involving porous catalysts or catalyst supports, diffusion occurs. The same process also is frequently controlling in material transfer between a granular solid and a fluid stream.

The field of diffusion in solids is of much interest to chemical engineers. Its importance and applications have already been well outlined in recent literature (*10, 17, 28, 30*). Several factors are increasing the need for basic work in this field. The rapid depletion of the richer ores of the country is emphasizing the importance of the knowledge of the theory as well as of the practice of leaching operations.

Attention can be called also to the accentuated importance given to diffusional operations through porous membranes by their use in the separation of isotopes. The recent development of effective methods for the calculation of mass- and heat-transfer rates from particle surfaces in beds of packed solids, such as in catalytic chambers or adsorption beds, now brings forward the need for an understanding, in some cases, of transfer processes from within the particles to the surface (*13, 17*). Recent evaluations of porous catalysts or catalyst supports have measured internal areas, pore diameters, permeabilities, and porosities (*16*). While these quantities are undoubtedly important it would seem that more emphasis should be given to the study of the rates at which materials can diffuse into or from a porous body.

Molecular diffusion in general has been the subject of a great number of theoretical and experimental investigations (*1, 6, 14*). Relatively few studies have been made of diffusion within porous solids (*2, 4, 7, 29*). In regard to the unit operation of extraction, theory is quite inadequate where diffusion is important. While some quantitative studies have been made (*2, 3, 27*), data on the rate of extraction of different materials are practically nonexistent. A review of transfer processes between granular solids and fluid streams has pointed out the need for experimental work in this field (*30*).

The influence of an inert porous solid upon diffusion rate has not been extensively investigated. Buckingham (*4, 9*), working with two or more gases, found that the diffusion rate is a function of the porosity of the packing. McBain and Liu (*20*) showed that when hydrochloric acid and sucrose were allowed to diffuse through a porous glass diaphragm, the diffusivities obtained, by comparison with potassium chloride diffusing under standard conditions, were independent of the nature and porosity of the diaphragm. In this case the average pore diameter was of the order of 10,000 molecular diameters. Cady and Williams (*7*) studied diffusion of urea through wood fibers. They stated that the diffusion rate was decreased principally by a mechanical blocking effect of the cell structure; the effect of cell wall friction on molecular motion was of much less importance. Boucher, Brier, and Osburn (*2*) found that the extraction of soybean oil from porous clay plates was a purely diffusional operation whose rate was decreased by the nature of the solid. They suggested the factors affecting rate to be the mechanical blocking by the solid, the drag on molecules due to the proximity to cell walls, and the tortuous path through the solid. Katz and Osburn (*18*) discussed structure as a variable in the application of diffusion theory to extraction and developed equations for several idealized types of solid structure. Straight capillaries perpendicular to or at an angle to the face, or leading from reservoirs, wedge-shaped solids and mixtures of capillary sizes and of two thicknesses of slab were treated. These authors pointed out that in the case of isotropic, uniformly porous solids the complexities of the structure did not permit calculation of the effect of this type of struc-

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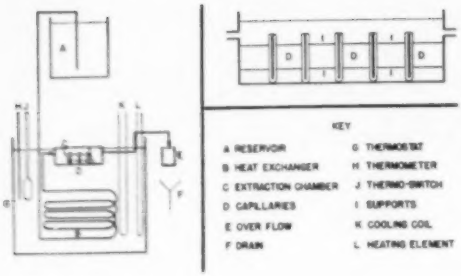

Fig. 1. Apparatus for extraction of solutions from capillaries.

ture on the rate of extraction. In summary it may be stated that although diffusion through porous solids has been studied experimentally in the above cases, it is difficult to isolate clearly the effect of the solid on the diffusion rate.

It was the purpose of the present work to obtain on idealized extraction systems further basic information on liquid diffusion rates which would be of value in the study of actual systems involving porous carrier solids. In this paper there will be presented theoretical equations and experimental data for extraction from single capillaries, from beds of uniform glass beads, and from inert porous spheres carrying single-phase solutions of soluble substances. A second paper will develop theoretical equations and present experimental data for two-phase systems within porous solids.

A solid-liquid extraction system is comprised of an inert solid carrier, soluble constituents in the carrier, and a suitable solvent. Effects which may be encountered in practice because of chemical reactions, carrier disintegration, or cell membrane resistances will not be considered here. It is here postulated that the solute is transferred through the capillaries of the solid entirely by diffusion. The solvent outside the solid is considered to be sufficiently well agitated to have at any instant a uniform concentration at all points.

For the case where diffusion is taking place into an infinite volume of solvent the necessary equations and suitable numerical solutions are available. Values have been tabulated by Newman for spheres, cylinders, and slabs (*22*). Where the solvent volume is limited the concentration rise therein becomes important in determining the rate. This latter condition is the more important in industrial operations. Hatta (*15*) has derived the equation for this case for a slab with sealed periphery. It was necessary at the time the present work was done to develop the desired theoretical and numerical solution for the case of spheres extracted by a finite volume of solution. More recently Paterson (*25*) has made available an alternate solution for heat transfer from spheres. Unfortunately his numerical values are not particularly applicable to the range desired for material diffusion problems. The derivation given here also served as a basis for the cases of parallel and counter-current continuous extraction.

In order to analyze extraction on the basis of a diffusion mechanism, applicable values of diffusivity for the solutes being extracted are needed. The fact that diffusivity is not a constant and that the unsteady state equation

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x} D\left(\frac{\partial C}{\partial x}\right)$$

has been solved mathematically for only the simplest boundary conditions discourages an attempt to use true or differential diffusivities to solve the present problem. A logical approach is to use selected integral diffusivities. Although the majority of diffusivities reported in the literature are integral values, the concentration ranges are generally for rather dilute solutions whereas in industrial applications the concentration will in many cases tend to be high. Only a few diffusivities of common inorganic salts have been given for the range from zero to nearly saturated concentrations. Moreover most values have been measured under conditions of free diffusion or near steady-state conditions rather than the restricted diffusion conditions

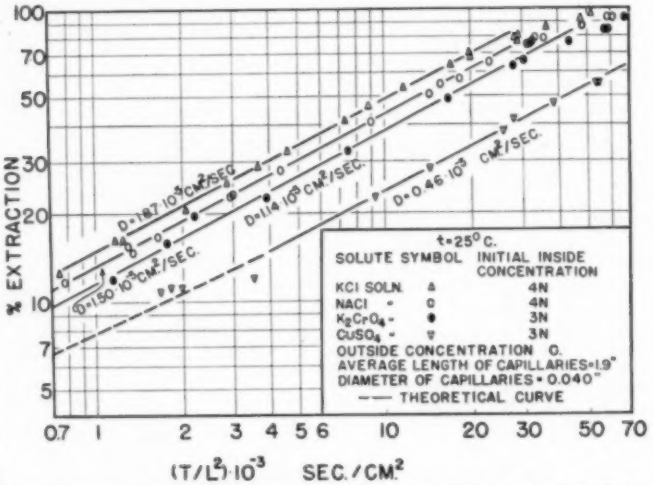

Fig. 2. Extraction of various single phase solutes from straight smooth capillaries using a continuous stream of distilled water as solvent.

TABLE 1

Single Phase Extractions from Capillaries and Bead-packed Tubes

Temperature = 25°C Outside concentration = 0 Length, L = 5 cm

Carrier solid: Glass capillaries, 0.1 cm ID			Glass tubes, 0.38 cm ID, packed with glass beads, 0.015 cm diameter; porosity, 39.4%			
Salt:	4 N. KCl		4N. NaCl		4 N. KCl		4 N. NaCl	
Initial inside conc., g/ml	0.300		0.237		0.300		0.237	
	t/L^2 sec/cm^2	100 - E %	t/L^2 sec/cm^2	100 - E %	t/L^2 sec/cm^2	100 - E %	t/L^2 sec/cm^2	100 - E %
	51.87 x 10^3	98.1	80.70x10^3	92.6	36.16x10^3	74.4	23.44x10^3	84.9
	36.50	85.8	49.21	86.2	25.86	64.7	18.68	48.5
	28.97	80.4	33.52	78.6	20.66	58.3	10.55	35.6
	17.03	63.2	25.50	66.2	12.64	45.8	8.69	31.8
	8.805	45.9	15.89	54.9	8.12	35.7	6.79	27.7
	3.689	28.8	8.954	41.0	3.64	24.1	3.26	18.0
	2.838	24.9	4.316	28.0				
	1.942	18.9	2.912	83.P				
	1.160	13.8	1.240	15.7				
	0.741	12.2	0.776	12.0				

obtaining in solid-liquid extraction systems. It was therefore desirable in this work to determine integral values of diffusion coefficient for nearly saturated solutions of a number of salts.

Single Capillary Investigations

A relatively simple technique using single straight capillary tubes was developed which permitted the evaluation of integral diffusivities over the concentration ranges desired. This consisted in filling capillary tubes with solutions of various solutes and determining the rate of extraction into a stream of distilled water flowing slowly past the top of the capillary. Several capillary tubes were used so that the amounts remaining after various measured times could be determined analytically. Each capillary provided one datum point of percentage unextracted at time t.

The new technique developed to obtain these data proved satisfactory; the main limitation on the accuracy lay in the analyses of the small quantities of material remaining in the capillaries.

Theoretical Equation for Extraction of Solutions from Capillary Tubes. This diffusion process is a case of restricted diffusion from a finite column to an infinite reservoir. The following equation is an exact solution for this case (*22*).

$$E = \frac{800}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \exp\left(\frac{-(2n-1)^2\pi^2 Dt}{4L^2}\right) \qquad (1)$$

Deviations between the solution to Equation (1) and experimental facts probably can best be attributed to the assumptions that D is constant and that volume changes are negligible.

H. Liebhafsky has discovered an approximate equation much simpler than Equation (1) and which is valid up to 50% extraction (*19*). His equation as applied to this case is

$$E = 100 - 200\sqrt{\frac{\pi Dt}{L^2}} \qquad (2)$$

Equation (2) suggests that experimental data be analyzed by plotting $(100 - E)$ vs. (t/L^2) on log-log paper. Straight lines of slope 0.5 should result from zero to well past 50% extraction.

Apparatus and Procedure. Precision-bore glass tube (one end sealed) capillaries 0.102 cm. I.D. and about 5 cm. long were used. The volume of the capillary was calculated from the dry weight of the tube, the weight when filled with water, and the density of water at 25° C. The internal length was obtained by measuring the projecting end of a slightly longer known length of copper wire with a cathetometer.

The extraction apparatus is shown in Figure 1. The capillaries were held in a vertical position with open end up in a stream of distilled water flowing slowly at right angles to the longitudinal axis of the capillary. The temperature was maintained at 25.0 ± 0.1° C. Runs were made in the following manner: A capillary was filled with stock solution using a hypodermic needle and was placed in the extraction chamber at zero time. At time t the capillary was removed, and the solution inside the capillary was washed into a flask or crucible and analyzed volumetrically or gravimetrically.

Experiments with Solutions in Capillary Tubes. The experimental data for the extraction of solutions of potassium chloride, sodium chloride, potassium chromate and copper sulfate from capillaries are presented in Figure 2. Extractions of acetic acid solutions are shown in Figure 3. Sample data are given in Table 1. These data are plotted on log-log paper with percentage extraction as the ordinate and the group (t/L^2) in seconds per square centimeter as the abscissa. It was necessary to use (t/L^2) as the time variable since the length of the individual capillaries varied within a range of ±6% from the average length. The theoretical curves were drawn in with a slope of 0.5 and the indicated values of diffusivity, D, were calculated from Equation (1). The value at 50% extraction was used since the precision and accuracy were best in this range.

The precision of the data is satisfactory. For the four salts and for 25% acetic acid the best curve through the points up to 50% extracted is a straight line. The slopes are close to but not exactly 0.5; this may indicate some variation of the integral diffusivity as extraction proceeds.

Figure 3 shows the divergence of the acetic acid data from a straight line. It is assumed that these deviations in slope are caused by changes in the value of D with concentration. From the data shown, integral diffusivities at various per cent extractions have been calculated and are shown on Figure 4. The integral diffusivity of glacial acetic acid at 8% extraction is 9.0×10^{-6} sq.cm./sec.; it drops sharply to 1.6×10^{-6} sq.cm./sec. at 25% extraction, and falls more gradually to 1×10^{-6} sq.cm./sec. at 50% extraction. Copper sulfate also shows a variation of integral diffusivity with per cent extraction.

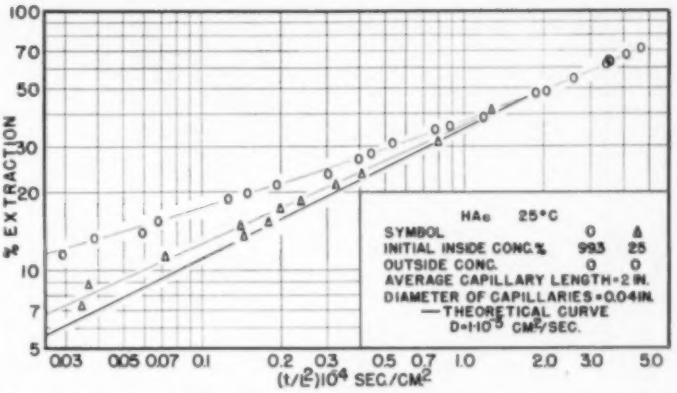

Fig. 3. Extraction of glacial acetic acid and a 25 per cent aqueous acetic acid solution from straight smooth capillaries using a continuous stream of distilled water as solvent.

Values of diffusivity obtained from the experimental data using Equation (1) are listed in Table 2 and compared with values estimated from recent literature data. The agreement is excellent for sodium chloride and potassium chromate and quite good for the other materials. It is significant that the integral diffusivities of sodium chloride and potassium chromate obtained from the literature were, as desired, for 4*N* and 3*N* solutions diffusing to distilled water. Only a temperature correction was necessary in these cases. Exact agreement in the other cases would be fortuitous since integral values corresponding to the experimental concentrations were not available.

Extraction from Beds of Close-Packed Spheres

The simpler case of straight capillar-

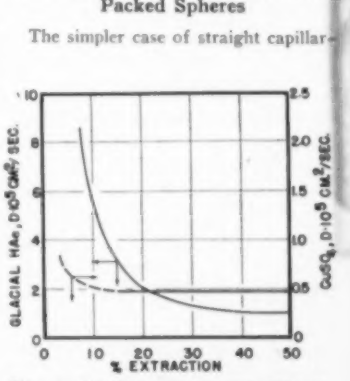

Fig. 4. Variations of integral diffusivities of glacial acetic acid and 3*N*. $CuSo_4$ diffusing from finite capillary tubes into a continuous stream of distilled water.

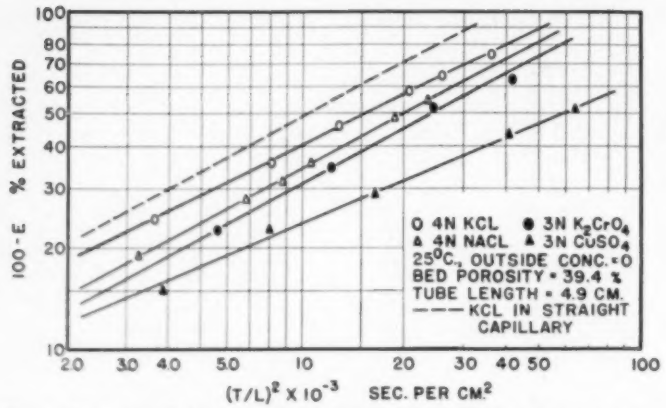

Fig. 5. Extraction of single phase solutes from beds of small glass beads into a continuous stream of distilled water.

ies having been considered, some experiments were made on the relatively more complex structure made up of close-packed spheres before going on to a typical material of practical importance.

In order to determine experimentally the effect of this simple type of porous medium upon the extraction process a series of extractions was performed in the same way as were the previous smooth bore capillary extractions but using as the carrier solid, close-packed glass beads contained within glass tubes 0.35 cm. I.D. by 5 cm. long (sealed at one end). The glass beads were 0.015 ± 0.002 cm. in diameter. Since the tube diameter was about 23 times the bead diameter the wall effect on the bed structure was probably small. Under a low power microscope almost all the glass beads appeared to be closely spherical.

The tubes were loaded with a mixture of beads and solution so as to obtain beds of uniform density free of air bubbles. The tubes were extracted in the same way as the single capillaries. Preliminary experiments were run to determine the total volume of each tube and the net volume of solution contained within the bed of close-packed spheres. The porosity of the beds of spheres was calculated from the quantity of solute at zero extraction, the concentration of the stock solution, and the total tube volume. The porosity was found to average $39.4 \pm 0.5\%$.

Sample data for potassium and sodium chloride are included in Table 1. All the data are shown in Figure 5. Solid lines are drawn through the points for each of the four salts, potassium chloride, sodium chloride, potassium chromate and copper sulfate. A broken line locates the previous data for potassium chloride diffusing from smooth bore capillaries. Some loss in precision occurred because of variations in the consolidation of the beds of glass beads. Nevertheless the curves are substantially parallel and have a slope close to 0.5 except for copper sulfate. Compared to the smooth bore capillaries they are all displaced to greater values of (t/L^2) for a given per cent extraction. At 50% extraction of the first three salts the average ratio of (t/L^2) for glass beads to smooth capillaries is 1.46 ± 0.04. It will be evident from subsequent discussion that this corresponds to a pore-shape factor of K^2 equal to 1.46. The fact that the copper sulfate data fall on a slope of 0.43 instead of 0.5 is an indication that the differential diffusivity of this salt is variable. Assuming a K^2 of 1.46, the integral diffusivity for copper sulfate is calculated as 0.51×10^{-6} sq.cm./sec. for the conditions of the experiment.

Results obtained may be of value with reference to catalyst supports made up of spherical particles.

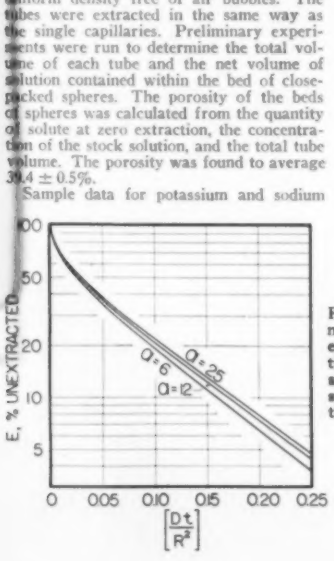

Fig. 6. Plot of numerical solution to equation (4) extraction of a single phase solute from porous spheres using solution ratios of 6, 12 and 25.

Porous Sphere Investigations

A series of experiments was carried out on the batch extraction of single-phase solutes from porous alumina spheres. This was done by filling the capillaries of the porous spheres with salt solutions and determining the rate of extraction into a measured volume of solvent. The purpose of these experiments was to determine the effect of the porous medium upon extractions and to check experimentally the validity of equations derived in this work for the case of spheres.

Theoretical Equation for Single-Phase Batch Extractions from Spheres. This is a case of restricted diffusion. Single-phase solute is contained in a porous sphere and the sphere placed into a finite quantity of agitated solvent. As the diffusion proceeds, the concentration in the outside solution rises. Hatta has solved this problem for a porous slab with a sealed periphery (*15*). In the present work an equation has been developed for spheres.

A sphere is postulated which, while insuring that diffusion controls at all times, offers no resistance to diffusion. The equation for symmetrical diffusion from a sphere of porosity P is

$$\frac{\partial Pc}{\partial t} = D\left(\frac{\partial^2 Pc}{\partial r^2} + \frac{2}{r}\frac{\partial Pc}{\partial r}\right)$$

or

$$\frac{\partial c}{\partial t} = D\left(\frac{\partial^2 c}{\partial r^2} + \frac{2}{r}\frac{\partial c}{\partial r}\right)$$

Defining a new variable $u = cr$, then

$$\frac{\partial u}{\partial t} = D\frac{\partial^2 u}{\partial r^2}$$

The boundary conditions are

$u = 0$ at $r = 0$
$u = c_o r$ when $t = 0$
$u = cr$ when $t > 0$
$c = c_o = C_x$ when $t = \infty$

TABLE 2

Comparison of Experimental Integral D with Estimated Literature D.

t = 25°C.

Substance	Concentration Range	Integral D Based on Data cm²/sec.	Estimated Literature D cm²/sec.		Authority
4N NaCl	0 to 4N	1.50×10^{-5}	1.48×10^{-5}	a	Burrage (5)
4N KCl	0 to 4N	1.87 "	1.84 "	b	Clack (8)
3N K_2CrO_4	0 to 3N	1.14 "	1.14 "	a	Oholm (23)
3N $CuSO_4$	0 to 3N	0.46 "	0.48 "	d	Oholm (24) Eversole (11)
HAc	0 to 99.3%	1.00 " c	1.26 " (0.05N to pure H_2O)		Roehl (26)

a Corrected to 25°C. using 0.025 as temperature coefficient

b Estimated from differential diffusivities

c Based on 50 per cent extraction

d Extrapolated from data for 0.1 to 2N solutions

$$-ADP\left(\frac{\partial c}{\partial r}\right)_{r=R} = \left(\frac{\partial C}{\partial i}\right)V \text{ at } r = R$$

The solution of this problem is:

$$\frac{c - c_\infty}{c_o - C_o} = -\frac{2}{3}\frac{aR}{r}\sum_{p=1}^{\infty}\frac{1}{\left[1 + a\left(1 + \frac{am_p^2}{9}\right)\right]\sin m_p} exp\left(\frac{-m_p^2 Dt}{R^2}\right)sin\left(\frac{m_p r}{R}\right) \quad (3)$$

where m_p is root of equation $tan\ m_p = \dfrac{1}{1 + \frac{a}{3}m_p^2}$

At $r = R$, $c = C$ and $c_\infty = C_\infty$

$$\frac{C - C_\infty}{c_o - C_o} = -\frac{2}{3}a\sum_{p=1}^{\infty}\frac{1}{\left[1 + a\left(1 + \frac{am_p^2}{9}\right)\right]} exp\left(\frac{-m_p^2 Dt}{R^2}\right)$$

and

$$E = \frac{C_\infty - C}{C_\infty - C_o}100.$$

Then

$$E = \frac{200}{3}(a)(a+1)\sum_{p=1}^{\infty}\frac{1}{\left[1 + a\left(1 + \frac{am_p^2}{9}\right)\right]} exp\left(\frac{-m_p^2 Dt}{R^2}\right) \quad (4)$$

and

$$\frac{\partial C}{\partial t} = \frac{2a(c_o - C_o)D}{3R^2}\sum_{p=1}^{\infty}\frac{m_p^2}{\left[1 + a\left(1 + \frac{am_p^2}{9}\right)\right]} exp\left(\frac{-m_p^2 Dt}{R^2}\right) \quad (5)$$

According to Equation (5) the absolute rate of extraction is directly proportional to the initial concentration gradient $(c_o - C_o)$. However, extraction data expressed as percentage unextracted at various measured times is unaffected by initial inside and outside concentration as shown by Equation (4). At any particular time the percentage unextracted depends only on the solution ratio, the sphere radius, and the diffusivity. The effect of variation of solution ratio is complicated. To show this effect, Equation (4) has been plotted for various values of solution ratio and is given in Figure 6. It can be seen that at low values, equilibrium is approached somewhat more quickly than at high values.

When the exponent $(m_p^2 Dt/R^2)$ becomes large, only the first term of the infinite series in Equation (4) is significant. The equation reduces to a simple exponential equation which gives straight line plots on semilog paper.

In the previous derivation an ideal sphere has been assumed. In practice, such porous spheres are not available. The capillaries in a porous sphere are tortuous and have many enlargements and constrictions. The increased length of path and the throttling effect of constrictions provide resistance to diffusion.

In fluid flow a valve is considered to be equivalent in resistance to a certain length of straight pipe. Here an actual sphere of radius R which usually has tortuous, constricted capillaries is considered to be equivalent to an idealized sphere of radius KR. $(K > 1.0)$ The square of this constant, K^2, will be called the pore shape factor. This factor, K^2, is also equal to the ratio of the actual to theoretical time (based on an ideal sphere) for a given per cent extraction. Equation (4) becomes

$$E = \frac{200a(a-1)}{3}\sum_{p=1}^{\infty}\frac{1}{\left[1 + a\left(1 + \frac{am_p^2}{9}\right)\right]} exp\left(\frac{-m_p^2 Dt}{K^2R^2}\right) \quad (6)$$

Table 3 presents numerical solutions to Equation (6).

It should be noted that use of the factor K in this way to characterize the resistance to diffusion of the porous solid is an arbitrary choice. An alternative method would be the use of an effective diffusivity, D'. This, however, has the disadvantage of loss of generality since D' would depend on both solute and solid and would be specific for each combination of the two. Moreover to use D' is somewhat misleading since it is not the diffusivity which is usually affected by an inert solid carrier but rather the effective length and cross-sectional area of the diffusion path.

It is plausible that porous spheres of different materials and even porous spheres of the same material may have different pore shape factors. Consider a 50-50 mixture of spheres of pore shape factors 4 and 14. In an extraction using a large volume of solvent, spheres of pore shape factor 4 will be extracted according to curve 4 (Fig. 7); spheres of pore shape factor 14 will follow curve 14. The observed curve will be the resultant of 4 and 14 shown as circles in Figure 7. The circles all lie within pore shape factor lines of 7 and 9. The circles follow closely the $K^2 = 7$ line to 40% unextracted. Below 40% unextracted the points curve upwards toward $K^2 = 9$. For lower solution ratios the effect of rising outside concentration must be considered. In this work the convention was adopted of taking the average K^2 value of a set such as in the above example to be the initial value 7. The curved tail of the points would be attributed to the mixing of spheres of different pore shape factors, and will be called a "mixture effect." Average pore shape factors of sets of porous spheres can be determined from extractions using a solute of known diffusivity.

Apparatus and Procedure. The porous media used in these experiments were tabular alumina spheres manufactured for use as catalyst supports and kindly furnished us by the Aluminum Ore Co. This material was selected because of its porous nature and its properties of insolubility, inertness, mechanical strength, and resistance to wear and high temperature. Suitable porous spheres of other sizes and porosities were, however, not available.

Ten pounds of balls nominally ¾ in. diameter and 25% porosity were obtained. After a preliminary elimination of rough and non-symmetrical balls, the porosity and average diameter of each of a group of approximately 900 balls were measured. Out of this group ten uniform sets of about 50 each were made up by means of a diameter-porosity chart so as to obtain the same distribution of porosities and diameters in each set. This procedure was found to be necessary in order to obtain good agreement of performance between sets. The average ball diameter for individual sets ranged from 1.195 to 1.199 cm.; the standard deviation of ball diameter within individual sets was between 0.042 and 0.056 cm. The average ball porosity

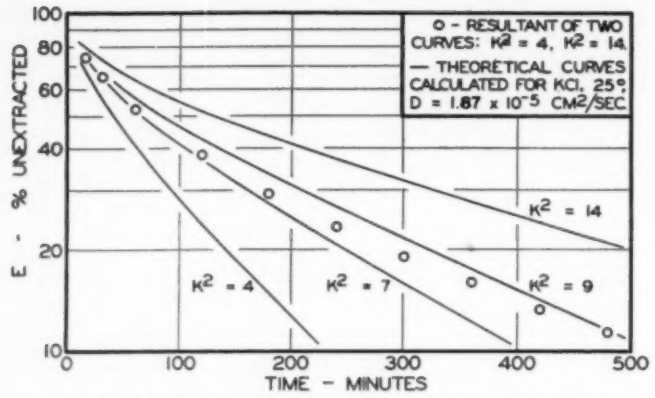
O - RESULTANT OF TWO CURVES: K² = 4, K² = 14
— THEORETICAL CURVES CALCULATED FOR KCl, 25°, D = 1.87 x 10⁻⁵ CM²/SEC.
K² = 14
K² = 4
K² = 7
K² = 9
E - % UNEXTRACTED
TIME - MINUTES

Fig. 7. Theoretical effect of mixing particles of different K^2 values.

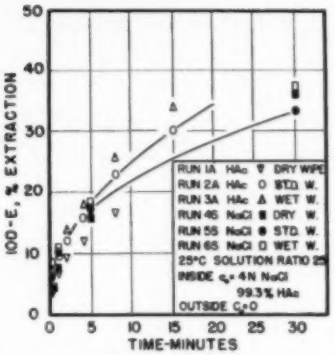
RUN 1A HAc ▼ DRY WIPE
RUN 2A HAc ○ STD. W.
RUN 3A HAc △ WET W.
RUN 4S NaCl ■ DRY W.
RUN 5S NaCl ● STD. W.
RUN 6S NaCl □ WET W.
25°C SOLUTION RATIO 25
INSIDE C_o = 4N NaCl
99.3% HAc
OUTSIDE C_o = 0
100-E, % EXTRACTION
TIME-MINUTES

Fig. 8. Effect of initial weight of solute film on porous alumina spheres on the extraction data obtained during early portion of regular extraction experiments.

and the standard deviation of ball porosity within individual sets ranged from 23.9 to 24.5% and from 3.8 to 4.2% respectively.

These sets were impregnated with liquids by placing the spheres in a flask, evacuating the flask to a pressure of about 5 mm. Hg., covering the balls with liquid and releasing the vacuum. The impregnated weight of the set was obtained by pouring off the excess solution, wiping the spheres on a cloth towel nearly saturated with the solution and weighing in a closed container. The porosity to water of the individual balls had been measured in this same manner. This procedure was found by experiment to give results reproducible to about 0.2%.

The extraction vessels used were one-pint glass mason jars with rubber gaskets. The balls were loosely held in the bottom of the jars with nichrome wire screens in order to reduce mutual abrasion and still allow free movement of the solvent around the spheres. Agitation of the solution was obtained by clamping the extraction jars to a rotor in the thermostat which caused continuous turning of the jar end over end at 2.53 rev./min. The sampling was done at selected times by taking the jar from the thermostat, removing one ball, and pipeting out its proportional part of solution. Mitchell (*21*) had shown that this technique had no appreciable effect on the extraction. The samples were analyzed either volumetrically or gravimetrically by standard procedures. Chemically pure chemicals and distilled water were used throughout. Sufficient data were obtained to make complete material balances. The average discrepancy in the balance, for single runs was 1.5%.

In a preliminary series of extraction experiments samples were taken at 15 and 30 sec., 1, 5, 30, and 120 minutes. In these experiments the sets of porous balls had been prepared for extraction so as to obtain different amounts or films of solution adhering to the external surface. Three films were used; a "wet" one was obtained by simply decanting the solute from the spheres after impregnation; a normal one was obtained by decantation followed by wiping the spheres with a cloth moistened with solution (this was identical with the procedure used in the standard runs); a dry one was obtained by decantation followed by a severe wipe with a cloth barely moistened with solution. The normal weight of solute impregnated into the spheres, using the standard procedure, was reproducible to 0.2%. The wet film corresponded to a 3% increase in weight of solute, and the dry film corresponded to a 4% decrease in weight. Results are plotted on rectangular coordinates (Fig. 8). The times plotted can be seen to be much shorter than the times used in regular runs. These early points indicate that at times approaching zero no sudden increase in transfer of material has occurred. This would not have been true if an appreciable amount of solute were free on the surface to diffuse without a porous media diffusion resistance. The latter points serve as a check on the validity of the runs since typical extraction curves were obtained.

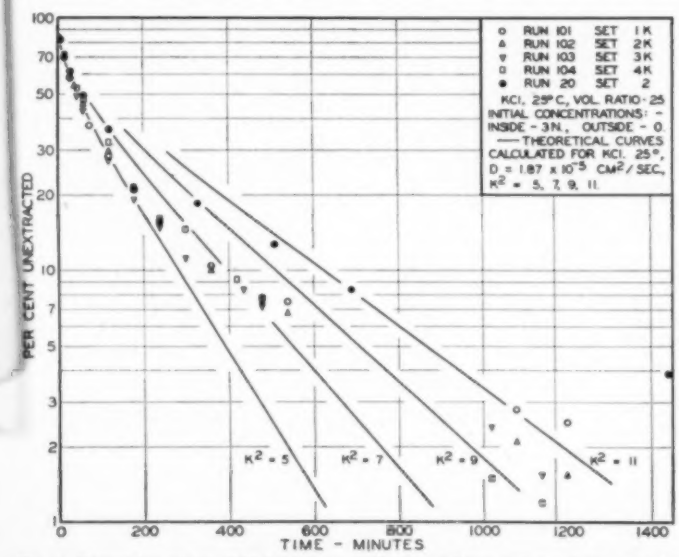
○ RUN 101 SET 1K
△ RUN 102 SET 2K
▽ RUN 103 SET 3K
□ RUN 104 SET 4K
● RUN 20 SET 2
KCl, 25°C, VOL. RATIO = 25
INITIAL CONCENTRATIONS: - INSIDE = 3N, OUTSIDE = 0
— THEORETICAL CURVES CALCULATED FOR KCl, 25°, D = 1.87 x 10⁻⁵ CM²/SEC., K² = 5, 7, 9, 11
K² = 5
K² = 7
K² = 9
K² = 11
PER CENT UNEXTRACTED
TIME - MINUTES

Fig. 9. Extraction of 3*N*. KCl from porous alumina spheres using a finite quantity of distilled water as solvent. Determination of pore shape factors of alumina porous spheres sets 1*K*, 2*K*, 3*K*, and 4*K*.

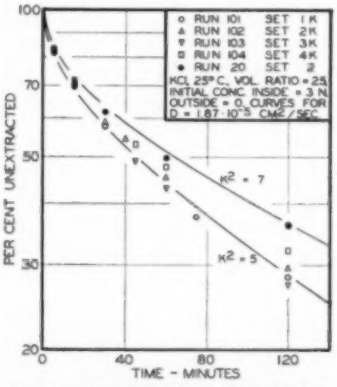
○ RUN 101 SET 1K
△ RUN 102 SET 2K
▽ RUN 103 SET 3K
□ RUN 104 SET 4K
● RUN 20 SET 2
KCl 25°C, VOL. RATIO = 25, INITIAL CONC. INSIDE = 3 N, OUTSIDE = 0, CURVES FOR D = 1.87·10⁻⁵ CM²/SEC.
K² = 7
K² = 5
PER CENT UNEXTRACTED
TIME - MINUTES

Fig. 10. Extraction of 3*N*. KCl solutions from porous alumnia spheres using a finite quantity of distilled water as solvent.

TABLE 3

Numerical Solution to Equation (6)

Values of Percent Unextracted versus Dt/K^2R^2 for Single Phase Sphere Equation

a, Solution Ratio

Dt/K^2R^2	a=6	a=12	a = 15	a = 21	a = 25
0.00300	79.76	81.13	81.38	81.67	81.78
0.00600	72.41	73.97	74.29	74.66	74.81
0.01200	63.51	64.53	64.92	65.38	65.55
0.01800	55.74	57.80	58.23	58.73	58.92
0.02400	50.32	52.47	52.91	53.43	53.64
0.03000	45.83	48.02	48.48	49.00	49.21
0.03600	41.98	44.19	44.65	45.19	45.41
0.04200	38.66	40.84	41.31	41.84	42.06
0.04800	35.71	37.86	38.32	38.86	39.07
0.05400	33.07	35.19	35.64	36.17	36.38
0.06000	30.69	32.77	33.21	33.73	33.94
0.06600	28.50	30.56	31.00	31.51	31.71
0.07200	26.55	28.54	28.96	29.47	29.67
0.07800	24.74	26.68	27.09	27.58	27.78
0.08400	23.07	24.96	25.37	25.85	26.03
0.09600	20.12	21.90	22.28	22.73	22.91
0.10800	17.60	19.25	19.61	20.04	20.21
0.12000	15.40	16.95	17.28	17.68	17.84
0.13200	13.49	14.94	15.25	15.62	15.77
0.14400	11.83	13.17	13.46	13.81	13.95
0.16200	9.72	10.91	11.17	11.48	11.61
0.18600	7.50	8.50	8.72	8.99	9.10
0.21600	5.42	6.23	6.41	6.63	6.71
0.26400	3.22	3.79	3.92	4.07	4.13
0.37200	1.01	1.24	1.29	1.36	1.39
0.79200	0.01	0.02	0.02	0.02	0.02

These experiments demonstrate that the extraction process was a smooth, continuing operation starting practically at zero time.

Experiments on the Extraction of Single-Phase Solutes from Porous Alumina Spheres.

Studies of Extraction with Inorganic Salts

A series of extractions was run in which were studied the effects of variations of initial inside and outside concentrations, solution ratio, and extraction temperature with potassium chloride solutions diffusing from porous tabular alumina spheres. The four sets of spheres which were used, were labelled $1K$, $2K$, $3K$, and $4K$. Typical extraction data are given in Table 4 for potassium chloride only.

The early runs were made with an initial outside concentration of zero and a $3N$ inside concentration for the purpose of determining pore shape factors for the four sets of alumina spheres. Results (Fig. 9) are plotted on semi-log paper with per cent unextracted as the ordinate and time in minutes as the abscissa. Theoretical curves of pore shape factors, K^2 equals 5, 7, 9 and 11, are shown as solid lines calculated from Equation (6) using an integral diffusivity of 1.87×10^{-5} sq.cm./sec. This diffusivity had been determined from the capillary experiments (Table 2). Data for a preliminary set 2 are also plotted to show the effect of porosity of alumina spheres on pore shape factors. Since this set had been made up of balls chosen at random its standard deviation of ball porosity was 7.0% instead of about 4.0% for the other sets. Thus set 2 was probably composed of spheres with a greater range of pore shape factors than the K sets. This greater range of pore shape factors should cause a relatively greater mixture effect. The increasing curvature of the data for set 2 in Figure 9 confirms this statement.

Figure 10 shows the same data on a larger scale. Using the fit of the data from 100 to 30% unextracted as a criterion, a pore-shape factor of 5 was obtained for sets $1K$, $2K$, and $3K$; a factor of 6 was assigned to $4K$.

Figure 11 shows the effect of variation of inside concentration. The plot is on semilog paper with percentage unextracted as the ordinate and the group (Dt/K^2R^2) as the abscissa. The initial inside concentrations were $4N$, $3N$, $2.25N$, and $1.5N$ KCl. All points fall close to a single theoretical curve. Thus it may be seen that variations of inside concentration have no effect on the data. This is in agreement with Equation (6). The study of the effect of outside concentration is not reported because the excessive precision of analytical procedures required by the presence of a large initial concentration, led to scattered data.

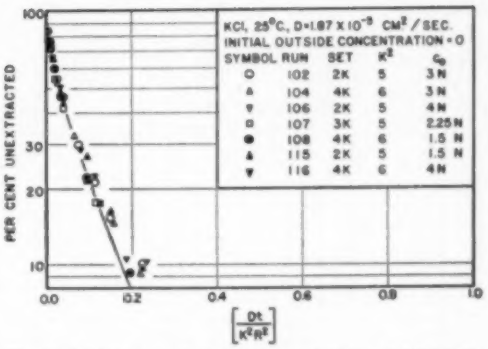

Fig. 11. Extractions of various concentrations of KCl solutions from porous alumina spheres using distilled water as solvent.

Figure 12 is a plot of three extractions with solution ratios of 9 and 25. The theoretical curves are shown as solid lines. The agreement is seen to be good.

The effect of temperature on the extraction of potassium chloride is shown in Figure 13. Knowing that the diffusivity of potassium chloride is 1.87×10^{-5} sq.cm./sec. at 25° C. and on the basis that K^2 is independent of temperature, one can use the relation $D_0/D_1 = t_1/t_0$ to compute the diffusivities at 50° C. and 0° C. from the time and percentage extraction data. These values of diffusivity are plotted (Fig. 14) on semi-logarithmic coordinates as suggested by the form of the theoretical relation, $D = A\ exp(-E_a/RT)$ (*12*). The straight line obtained is additional evidence that molecular diffusion is the controlling transfer mechanism in these extractions. It is important to note that the diffusivity obtained at 0° C. (*8*) and also the temperature coefficient are in good agreement with values available in the literature.

Using the group (Dt/K^2R^2) as the abscissa, extractions for potassium chloride, sodium chloride, potassium chromate and copper sulfate solutions are plotted on Figure 15. The experimental points fall on the theoretical curve within experimental error. The integral diffusivities of sodium chloride, potassium chloride and potassium chromate solutions used in

TABLE 4

Extraction of Aqueous Potassium Chloride from Porous Spheres

Salt: KCl	Initial outside concentration = 0		Carrier solid: porous spheres, set 4K		
Run No. :	104	108	116	126	127
Temperature, °C :	25	25	25	0	50
Initial inside conc., g/ml :	0.224	0.114	0.307	0.224	0.224
Solution ratio :	25	25	25	25	25

t min	100-E %	t min	100-E %	t min	100-E %	t min	100-E %	t min	100-E %
5	16.3	10	24.1	20	33.8	10	17.8	10	31.7
15	20.2	30	40.4	60	49.4	30	28.2	30	50.4
45	40.9	60	54.0	150	71.6	60	40.0	60	65.2
60	52.2	180	78.0	240	88.3	180	62.7	90	73.7
120	67.8	375	90.8	360	89.5	360	79.4	120	80.2
180	78.6	540	95.6	600	95.0	1080	92.7	150	85.0
240	82.6	1380	99.0	720	95.4	1800	96.5	180	88.0
300	85.4							240	93.0
480	92.3							360	97.7
1140	98.8							1320	100.5

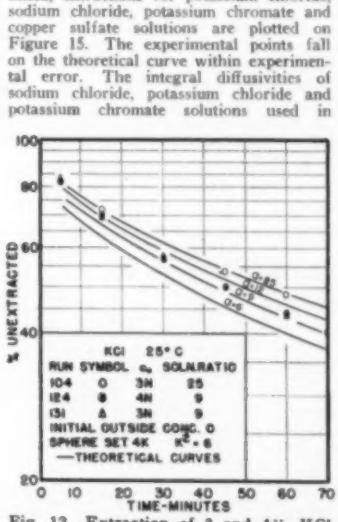

Fig. 12. Extraction of 3 and $4N$. KCl solutions from porous alumina spheres using various quantities of distilled water as solvent.

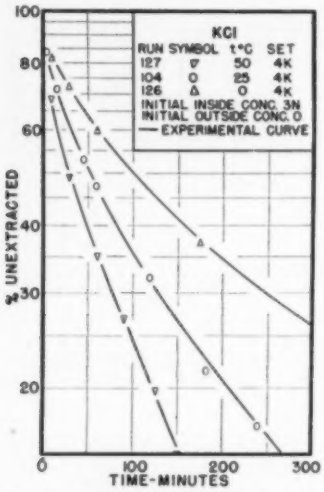

Fig. 13. Extraction of 3*N*. KCl solution from porous alumina spheres at various temperatures using distilled water as solvent.

evaluating (Dt/K^2R^2) were those obtained from the capillary determinations (Table 2). The estimated integral diffusivity for copper sulfate for these experiments is 0.8×10^{-6} sq.cm./sec.

Results of all the extractions of inorganic salts are replotted in Figure 16. For each salt the reciprocal of the time required to reach a given per cent extraction is plotted as abscissa with the values of D as ordinate. As required by Equation (6), for each value of per cent extracted the points do fall on a straight line passing through the origin. As D approaches zero, the extraction time approaches an infinite value. This plot shows that the extraction mechanism was solely diffusional. The fact that straight lines are obtained also shows clearly that the effect of the porous solid upon diffusion rate was a constant.

In summary, the experiments in study of solution ratio and variation of inside concentration confirm Equation (6). Diffusivities calculated from extractions at 0° C., 25° C., and 50° C. were correlated as predicted by physical theory. Pore shape factors were determined which successfully correlated the results of the extractions of sodium chloride, potassium chloride and potassium chromate solutions.

A Study of the Extraction of Acetic Acid. Capillary extraction experiments showed that the integral diffusivity of acetic acid varied ninefold or more in diffusing from a capillary of initial concentration 99.3% acid into pure water to a final average concentration of 10% acid into pure water. The following data are therefore cases of extraction of a material of variable diffusivity from porous spheres. The sets used in this study were 5*E*, 6*E*, 7*E*, and 8*E* and having been selected in the same manner as the *K* series were considered to have also a pore shape factor of 5.

Runs in which the initial inside concentration was 99.3% acetic acid and the initial outside concentration was zero are shown in Figure 17 on a semilog plot. The theoretical curve which fits the early data best was calculated using an integral D of 7×10^{-6} sq.cm./sec. and a K^2 of 5. Here, as in the extractions of copper sulfate solutions from porous spheres, only qualitative agreement with the capillary extractions is obtained. In the early stages of extraction of acetic acid from single capillaries an integral D as high as 9×10^{-6} sq.cm./sec. was determined. Since the early portion of capillary extraction is similar to sphere extractions the D of 7×10^{-6} sq.cm./sec. is not unreasonable.

Figure 18 shows the data on variation of inside concentration. The inside concentrations of the runs were 99.3%, 75%, 50%, and 25% acetic acid. There is no apparent significant effect.

The effect of solution ratio is given in Figure 19. Runs with solution ratios of 6, 9, 12 and 23 are plotted in Figure 19 on semilog paper. The extraction curves are close together. The curve for a solution ratio of 23 is uppermost followed in descending order by solution ratio curves 12, 9 and 6.

In these experiments the mixture effect clouds the influence of variable diffusivity. In any event it is probably difficult to apply integral diffusivities accurately for systems where differential diffusivities are known to vary greatly with concentration or concentration gradient.

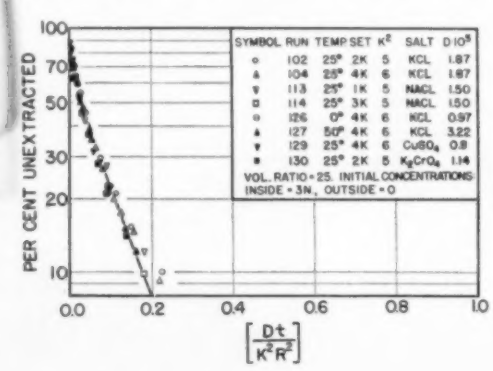

Fig. 15. Extraction of various common inorganic salt solutions from alumina spheres using distilled water as solvent.

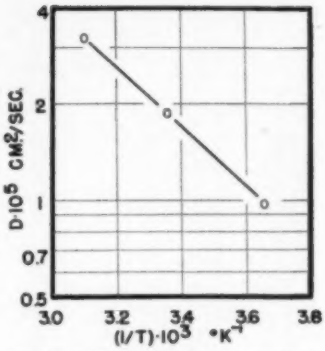

Fig. 14. Diffusivities observed at 40 per cent unextracted in Fig. 14 plotted as a function of absolute temperature.

Continuous Extraction Theory

Equation for Single Phase Countercurrent and Parallel Extractions from Spheres. The problem to be considered is presented in Figure 20(*a*). Porous spheres of radius R, containing a solution of uniform concentration c_o enter an extraction tower with a velocity v_1. The path of the spheres through the tower is finite of height H, hence the spheres leave, containing a solution of average concentration c'_H.† On the other hand, solvent of concentration C_H enters the unit with a velocity v_2 and leaves with a concentration C_o. The practical problem is then: given c_o, c'_H, C_o, and C_H, what is the height of the tower, or given H, c_o, C_o, and C_H, what is the average concentration of solution in the outgoing spheres?

To solve this problem an infinite section is visualized added to the bottom of the tower. Figure 20(*b*) pictures these conditions. As before, porous spheres of concentration c_o enter the tower; at height H the average concentration is c'_H, and at infinity the con-

† Same as $\bar{c}$ in Fig. 20.

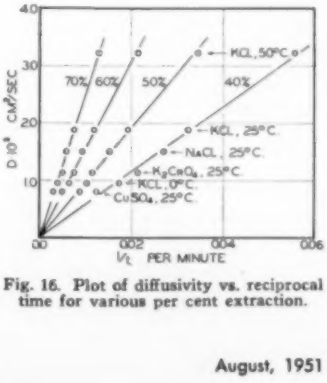

Fig. 16. Plot of diffusivity vs. reciprocal time for various per cent extraction.

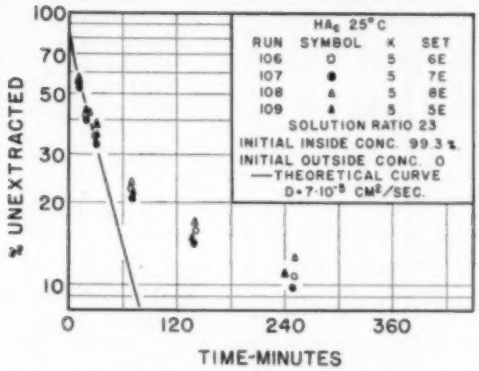

Fig. 17. Extraction of glacial acetic acid from porous alumina spheres using distilled water as solvent.

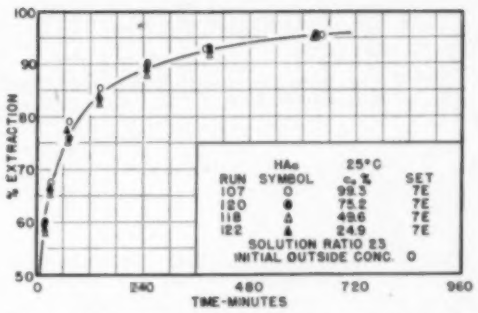

Fig. 18. Extraction of various concentrations of acetic acid solution from porous alumina spheres using distilled water as solvent.

centration is $-c_\infty$. The solvent now enters at concentration $-C_\infty$, increases to C_H at height H and leaves at concentration C_o at height zero.

Differential Equation and Boundary Conditions. This problem can be solved by considering the passage of a single sphere through the tower and applying the same technique as for the solution of the batch extraction problem. Let the time t be zero when sphere ζ enters the tower. Then when sphere ζ is at any height h the time of extraction is

$$t = \frac{h}{v_1}$$

Assuming Fick's law is valid, one obtains as before,

$$\frac{\partial u}{\partial t} = D\,\frac{\partial^2 u}{\partial r^2}$$

for which the boundary conditions are

$u = 0$ at $r = 0$
$u = c_o r$ when $t = 0$
$u = cr$ when $t > 0$
$c = -c_o = -C_\infty$ when $t = \infty$

The boundary condition at $r = R$ is obtained by making a material balance over an infinitesimal section dh of the tower.

The number of spheres entering and leaving dh in time dt is $Sn v_1 dt$; n is the number of spheres per unit tower volume. The solvent entering and leaving section dh in time dt is $-Sv_2 dt$.

The change in average concentration c' of one sphere as it passes through section dh is

$$dc' = \frac{-3D}{R}\left(\frac{\partial c}{\partial r}\right)_{r=R} dt$$

Material balance:

$$\left(\frac{4}{3}\pi R^3 P\right)(Sn v_1 dt)\left[\frac{-3D}{R}\left(\frac{\partial c}{\partial r}\right)_{r=R} dt\right] = (-Sv_2 dt)(-dC)$$

where P is the porosity of the spheres.

$$4\pi K^2 n P D\left(\frac{\partial c}{\partial r}\right)_{r=R} = \frac{-v_2}{v_1}\frac{dC}{dt}$$

$$= \frac{-v_2}{v_1}\left(\frac{\partial c}{\partial t}\right)_{r=R}$$

The solution of the problem is:

$$E' = \frac{2}{3}(a)(a-1)\sum_{p=1}^{\infty}\frac{1}{\left[1 - a\left(\frac{1 - am_p^2}{9}\right)\right]} exp\left(\frac{-m_p^2 DH}{K^2 R^2 v_1}\right) \qquad (7)$$

where

$$E' = \frac{C + C_\infty}{C_o + C_\infty}$$

and m_p are roots of equation

$$tan\ m_p = \frac{m_p}{1 - \frac{am_p^2}{3}}$$

Note that the concept of a pore shape factor has been included in Equation (7).

Then by material balances

$$c'_H = \frac{a(c_o - C_o)E' - (c_o - aC_o)}{a - 1} \qquad (8)$$

and

$$C_H = \frac{c_o - aC_o + E'C_o(2a - 1) + c_o - aC_o}{(a - 1)} \qquad (9)$$

To use Equation (7) with facility a numerical solution will have to be made giving values of E' for particular values of solution ratio a and for the dimensionless ratio $(Dh/K^2R^2v_1)$. Provided such a table becomes available the solution of countercurrent extraction problems will be quite simple. Given the radius of the spheres, the pore shape factor, the velocities of the solvent and spheres, the diffusivity of the solute, the height of tower, and the cross-sectional area of the extraction unit, E' is fixed. Then since outlet solvent and the inlet solute concentration in the spheres is usually given, c'_H and C_H can be computed from Equations (8) and (9). There are a number of problems possible because of the 11 dependent variables and two independent variables involved. However, they can be solved in a manner similar to that outlined above.

For the case of parallel extraction, the same equations are used. The direction of the solvent velocity is reversed so that when the solution ratio is calculated as outlined above, the value found is negative and should be used that way. It is important to note that the equation is not valid for solution ratios less than one or for either v_1 or v_2 equal to zero.

This solution appears to have direct application to heat-transfer problems as in pebble heaters and may be of use in continuous catalytic processes where diffusion controls.

Notation

a = solution ratio, volume of outside solution per unit volume of solution in porous spheres

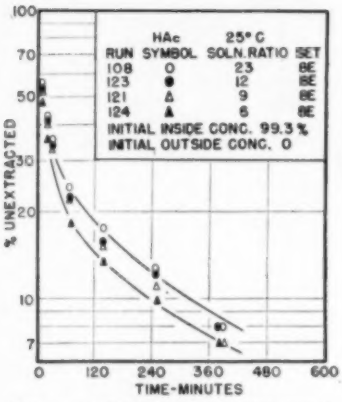

Fig. 19. Extraction of glacial acetic acid from porous alumina spheres using various quantities of distilled water as solvent.

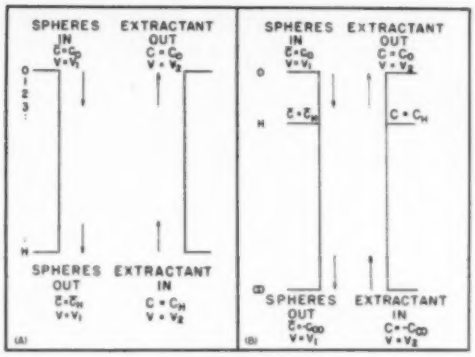

Fig. 20. Countercurrent extraction towers (A) of finite height and (B) of infinite height.

(NOTE: $\bar{c}$ coincides with c' in manuscript.)

A = area, sq.cm.
A' = a constant
c = concentration of inside solution at any point r and time t, g./cc.
c_o and c_∞ = concentration of inside solution at $t = 0$ and $t = \infty$, respectively, g./cc.
c'_H = mean concentration of solution in porous spheres as they leave parallel or countercurrent extraction unit
C = concentration of outside solution at any time, g./cc.
C_H = concentration of solvent entering countercurrent extraction unit, or in case of parallel extraction, concentration of solvent leaving extraction unit
C_o and C_∞ = concentration of outside solution at $t = 0$ and $t = \infty$, respectively, g./cc.

$$C_\infty = \frac{aC_o + c_o}{1 + a}$$

for batchwise extraction

$$C_x = \frac{c_o - aC_o}{a - 1}$$

for parallel and countercurrent extraction

D = diffusivity constant, sq.cm./sec.
E = per cent of extractable material remaining unextracted
E_a = observed activation energy
E' = intermediate variable, similar to E, used in solution of parallel and countercurrent extraction problems
h = distance from any point in an extraction tower to top of tower
H = height of an extraction tower
K^2 = pore shape factor of porous media
L = capillary length, cm.
m_p = roots of equation

$$\tan m_p = \frac{1}{1 + \frac{a}{3} m_p^2}$$

N = normality
n = number of spheres per unit volume of tower
n = integers 1, 2, 3, . . .
P = porosity of porous media, ratio of void volume to total volume
r = radius at any point in a sphere, cm.
R = radius of a sphere, cm.
R = gas constant
S = cross-sectional area of tower
t = time
T = temperature, abs., °K.
u = substitution variable, $= cr$
V = volume of external solution, cu.cm.
v_1 = linear velocity of porous spheres (positive downwards)
v_2 = linear velocity of solvent (positive upwards)
ρ_s = density of saturated solution, g./cc.
∞ = symbol for infinity
1, 2 = subscript numbers refer to different temperatures

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Literature Cited

1. Annals *N. Y. Acad. Sci.*, **46**, 209 (1945).
2. Boucher, D. F., Brier, J. C., and Osburn, J. O., *Trans. Am. Inst. Chem. Engrs.*, **38**, 967 (1942).
3. Brier, J. C., Katz, D. L., and King, C. O., *Trans. Am. Inst. Chem. Engrs.*, **40**, 533 (1944).
4. Buckingham, Edgar, U. S. Dept. Agriculture, Bureau of Soils, Bull. No. 25 (1904).
5. Burrage, L. J., *J. Phys. Chem.*, **36**, 2166 (1932).
6. Cady, L. C., and Williams, J. W., *Chem. Rev.*, **14**, 171 (1934).
7. Cady, L. C., and Williams, J. W., *J. Phys. Chem.*, **39**, 87 (1935).
8. Clack, B. W., *Proc. Phys. Soc. London*, **36**, 313 (1924); *Ibid.*, **29**, 49 (1916).
9. Dalavalle, J. M., Micromeritics, New York, Pitman Publishing Corp., pp. 105, 107, 121 (1943).
10. Donald, M. B., *Trans. Inst. Chem. Engrs.* (London), **15**, 77 (1937).
11. Eversole, W. G., Kindsvater, H. M., and Peterson, J. D., *J. Phys. Chem.*, **46**, 370 (1942).
12. Eyring, H., Irish, E. M., and Stearn, A. E., *J. Phys. Chem.*, **44**, 981 (1940).
13. Gamson, B. W., Thodos, G., and Hougen, O. A., *Trans. Am. Inst. Chem. Engrs.*, **39**, 1 (1943).
14. Harned, H. S., *Chem. Rev.*, **40**, 462 (1947).
15. Hatta, S., *J. Soc. Chem. Ind., Japan*, **39**, Suppl. binding, 486 (1936).
16. Heinmann, H., Krieger, K. A., and McCarter, W. S., *Ind. Eng. Chem.*, **38**, 839 (1946).
17. Hougen, O. A., and Watson, K. M., *Ind. Eng. Chem.*, **35**, 529 (1943).
18. Katz, D. L., and Osburn, J. O., *Trans. Am. Inst. Chem. Engrs.*, **40**, 511 (1944).
19. Liebhafsky, H. A., *J. Applied Physics*, **12**, 270 (1941).
20. McBain, J. W., and Liu, T. H., *J. Am. Chem. Soc.*, **53**, 59 (1931).
21. Mitchell, G. E., Ph.D. Thesis, Dept. of Chem. Eng., Univ. of Minn. (1940).
22. Newman, A. B., *Trans. Am. Inst. Chem. Engrs.*, **27**, 310 (1931).
23. Oholm, L. W., *physik. Chem.*, **70**, 378 (1910).
24. Oholm, L. W., Soc. Sci. Fennica, Commentationes Phys.-Math., **12**, No. 3, 1 (1943).
25. Paterson, S., *Proc. Phys. Soc.*, **59**, 50 (1947).
26. Roehl, E. J., King, C. V., and Kipness, S., *J.Am.Chem.Soc.*, **63**, 284 (1941).
27. Sullivan, J. D., *Trans. Am. Inst. Mining Met. Engrs.*, **106**, 515 (1933).
28. Symposium on Diffusion, *Ind. Eng. Chem.*, **33**, 424 (1941).
29. Thiele, E. W., *Ind. Eng. Chem.*, **31**, 916 (1939).
30. Thiele, E. W., *Ind. Eng. Chem.*, **38**, 646 (1946).

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THERMODYNAMIC PROPERTIES OF ETHYL ALCOHOL

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An extensive literature search revealed that the common thermodynamic properties of ethyl alcohol were unavailable. This paper presents a tabulation of volume, entropy, enthalpy, and fugacity from 32° F. and 0.238 lb./sq.in.abs. to the critical point, 469.4° F. and 928 lb./sq.in.abs. in 10° F. temperature increments. The results are also shown graphically on a pressure-enthalpy diagram. The saturated liquid, saturated vapor, and superheated vapor regions are included.

The entropy, enthalpy, and fugacity were computed from existing pressure-volume-temperature data and spectroscopic information. The consistency of the calculations were checked in as many ways as possible. Comparison of the entropies and enthalpies with the meager experimental data that exist indicates agreement within 1.0%.

THIS paper represents a continuation of a project for evaluating the thermodynamic properties of industrially important, oxygenated, organic compounds. Previous investigations have been concerned with methyl alcohol (*36*), acetaldehyde (*9, 35*), and ethylene oxide (*23*).

Since ethyl alcohol is commonly used in the chemical process industries, a treatment of its thermodynamic properties should prove useful. Many investigators have carried out experiments on ethyl alcohol, but most of the work has been to study its chemical and physiological behavior and not to provide useful data to the design engineer. In this paper the specific volume, enthalpy, entropy, and fugacity of ethyl alcohol are presented in tabular and graphical forms.

Available Data. It is customary to calculate a complete set of thermodynamic properties with experimental volumetric and thermal data. The volumetric information should include sufficient and accurate pressure-temperature-volume measurements to encompass the desired region. The thermal data should relate the heat capacity as a function of temperature at a constant pressure (or volume) over the desired temperature range.

Volumetric data for ethyl alcohol were given in two principal sources. Ramsey and Young (*29*) and Battelli (*3*) measured the specific volume at various temperatures and pressures. Ramsey and Young worked in the temperature range from 90° C. to 246° C. and Battelli from −16° C. to 245° C. No additional volumetric data above the critical temperature (243.1° C.) could be found (*43*). Several other investigators (*13, 40, 41*) did some experimental volumetric work, but their results were either too sparse or unavailable at this time. Specific volumes of the saturated liquid and vapor, as well as heats of vaporization and vapor pressures were taken from the work of the Bureau of Standards (*11*) up to 130° C. and from the values of Ramsey and Young (*29*) and Regnault (*30*) from 78° C. to the critical temperature. Kirejew (*18*) and Young (*43*) expressed the vapor pressure as a function of temperature.

Little experimental heat capacity data are given in the literature. Neyreneuf (*24*) and Jatkar (*16*) calculated C_p values from experiments on the velocity of sound in ethyl alcohol vapor. Other heat capacity studies in the vapor region (*4, 10, 11, 19, 31*) do not cover a wide range of temperatures or pressures. Many investigators (*2, 32, 37*) have made spectroscopic measurements and calculated the ideal gas properties of ethyl alcohol. The most recent work was done by the Bureau of Standards (*7*). They tabulated values of the entropy, enthalpy, heat capacity, and free energy for the ideal gas in an extensive table with a temperature range of 298° K. to 1500° K. Spencer (*38*) fitted the heat capacity data to an empirical equation by the least squares method. It is this equation that was used in all heat capacity calculations.

Although no calculations were made in the liquid region, the literature search uncovered many references both to the volumetric and thermal properties of the liquid. Bridgeman (*8*) determined several thermodynamic quantities including isothermal compressibilities, variation of internal energy with both temperatures and pressure, besides pressure-temperature-volume data, covering the temperature range of 20° C. to 80° C. and with pressures ranging up to 12,000 kg./sq.cm. Rakovskii (*28*) and other workers (*14, 20, 34*) provide extensive tables at lower temperatures. At higher temperatures and pressures, volumetric data were obtained by Ramsey and Young (*29*), Amagat (*1*), and Tammann (*39*).

Most of the investigations of the thermal properties of liquid and solid ethyl alcohol were carried out to provide a basis for calculating absolute entropies for use in chemical reaction equilibria problems. Numerous references (*3, 12, 17, 22, 26, 27*) have tabulated heat

NOTE: Complete Tables 1 and 2 are on file (Document 3316) with American Documentation Institute, 1719 N Street, N.W., Washington, D. C. Obtainable by remitting $1.00 for a microfilm and $2.85 for photocopies.

TABLE 1

THERMODYNAMIC PROPERTIES OF SATURATED ETHYL ALCOHOL

Temp. °F.	Pressure psia	Sp. Vol.-Cu.ft./lb. Sat. Liq.	Sp. Vol.-Cu.ft./lb. Evap.	Sp. Vol.-Cu.ft./lb. Sat. Vap.	Enthalpy-Btu/lb. Sat. Liq.	Enthalpy-Btu/lb. Evap.	Enthalpy-Btu/lb. Sat. Vap.	Entropy-Btu/lb.-°F. Sat. Liq.	Entropy-Btu/lb.-°F. Evap.	Entropy-Btu/lb.-°F. Sat. Vap.	Fugacity Coefficient Sat. Vap. = f/p
32	0.238	0.01946	473.5	473.5	0.0	407.2	407.2	0.0	0.8281	0.8281	0.999
40	0.319	0.01946	360.6	360.6	4.4	405.3	409.7	0.0089	0.8111	0.8200	0.991
50	0.459	0.02007	255.3	255.3	9.8	403.0	412.8	0.0196	0.7907	0.8103	0.990
60	0.647	0.02020	184.3	184.3	15.4	400.5	415.9	0.0304	0.7706	0.8010	0.989
70	0.910	0.02033	135.2	135.2	21.0	397.9	418.9	0.0411	0.7512	0.7913	0.988
80	1.26	0.02045	98.82	98.84	26.9	395.1	422.0	0.0521	0.7321	0.7842	0.987
90	1.71	0.02057	73.30	73.32	32.9	392.2	425.1	0.0631	0.7135	0.7766	0.985
100	2.30	0.02070	55.25	55.27	39.0	389.0	428.0	0.0741	0.6950	0.7691	0.984

TABLE 2

THERMODYNAMIC PROPERTIES OF SUPERHEATED ETHYL ALCOHOL

Temp. °F. (Sat. Press., Psia)	Sat'd. Vapor	Absolute Pressure (psi)						
		0	0.1	0.2	0.3	0.4	0.6	0.8
32 (0.180)	V	476.5	------	1139	566.9			
	H	407.0	430.4	430.1	407.6			
	S	0.8281	------	0.8073	0.8338			
	f/p	0.980	1.000	0.996	0.993			
40 (0.324)	V	360.5	------	1156	577.4			
	H	409.7	433.4	431.3	411.3			
	S	0.8030	------	0.8043	0.8127			
	f/p	0.981	1.000	0.997	0.994			
60 (0.599)	V	265.1	------	1182	589.0	702.3	703.4	
	H	437.8	457.2	456.3	435.4	431.7	431.7	
	S	0.8229	------	0.8215	0.8502	0.8320	0.8172	
	f/p	0.980	1.000	0.997	0.995	0.993	0.991	

		0	14.7	30	60	100	150	200
200 (460)	V	0.282	------	13.57	6.837	3.795	1.968	1.263	0.915
	H	512.9	573.9	573.7	571.6	570.4	568.2	563.7	558.1
	S	0.6854	------	0.8993	0.8547	0.8334	0.8097	0.7863	0.7680
	f/p	0.917	1.000	0.989	0.978	0.964	0.953	0.956	0.969

capacities as a function of temperature from liquid helium temperatures to 298° K. In the liquid region from 30° C. to 70° C., Blacet, Leighton and Bartlett (*5*) accurately determined similar information. Earlier work (*6, 25, 42*) lists experimental heat capacity values in the range −20° C. to 100° C. The International Critical Tables (*15*) have published liquid heat capacity values from −100° C. to 150° C. at the vapor pressure of ethyl alcohol.

The Bureau of Standards published a comprehensive bibliography on the physical properties of ethyl alcohol (*21*) covering the years 1769 to 1913.

Calculation Methods. The calculation of fugacity coefficients, entropies, and enthalpies were made from thermodynamic relationships involving the residual volume, defined as $a = RT/P - V_o$. Values of a were calculated from both sets of volumetric data (*3, 29*) and plotted on large graphs against the system pressure on lines of constant temperature. Ramsey and Young's values gave smooth curves in every case and permitted an extrapolation to zero pressure. Battelli's values plotted erratically in some cases, but by using Ramsey and Young's values as a guide and Battelli's values as a measure of the magnitude, smooth curves were drawn and extrapolated to zero pressure. The smoothed values of the residual volume as taken from the graphs were then used to calculate specific volumes at even increments of temperature (° F.) and pressure (lb./sq.in.abs.). These values are tabulated in Table 2.

The residual volume-pressure curves were also used to calculate the fugacity coefficients (fugacity-pressure ratio) by utilizing the equation,

$$\ln f/P = -(1/RT)\int_o^P a\,dP \qquad (1)$$

Integration under the residual volume-pressure curves permitted the calculation of the fugacity coefficient for the entire superheated vapor region. These calculated values were plotted on a large log P vs. f/P graph at constant temperature and smoothed. The final results are tabulated in Table 2.

The entropy and enthalpy of saturated ethyl alcohol liquid at 32° F. were chosen equal to zero. The entropy of the saturated vapor at 32° F. was determined from the equation,

$$\Delta S_v = \Delta H_v/T \qquad (2)$$

The ideal-gas entropy at unit fugacity and 32° F. was then calculated in order to be able to use ideal-gas heat capacity results for evaluating entropies at other temperatures. By expanding the gas from the vapor pressure to zero pressure and then compressing it as an ideal gas to one atmosphere, this entropy may be determined from the expression

$$S^\circ = S_{vp} + R\ln P_{vp} - \int_o^{P_{vp}} (\partial a/\partial T)_p dP \qquad (3)$$

A large plot of a vs. T was constructed and this graph used to measure the necessary slopes $(\partial a/\partial T)_p$. The values of these slopes were plotted against pressure and smoothed. From the latter curves, the integral in Equation (3) was calculated by graphical means.

Once the entropy of the hypothetical ideal gas at unit fugacity had been calculated, ideal gas entropies at higher temperatures, but at the same pressure, were determined from the expression,

$$dS^\circ = (Cp^\circ/T)dT \qquad (4)$$

Using the heat capacity equation of Spencer (*38*), this becomes,

$$dS^\circ = \frac{(4.946 + 49.087\times10^{-3}T - 238.55\times10^{-7}T^2 + 4.500\times10^{-9}T^3)dT}{T}$$

Integration gave ideal gas entropies from 32° F. to the critical temperature at a pressure of one atmosphere. To determine actual entropies in the vapor region at different pressures, isothermal calculations were carried out at even temperature increments using the S° values determined from Equation (4). To perform this calculation, Equation (3) was rearranged and solved for S_{vp} which now became the entropy of ethyl alcohol vapor at any pressure P_{vp}. P_{vp} varied between zero and the vapor pressure at the temperature at which the calculation was made. Designating $S_{vp} = S$ and $P_{vp} = P$, the equation would be

$$S - S^\circ = \int_o^P (\partial a/\partial T)_p dP - R\ln P \qquad (5)$$

Using the S° values from Equation (4), values of S were calculated throughout the vapor region at even increments of temperature up to the critical temperature. The results are illustrated in Table 2.

Entropies of vaporization, calculated from heats of vaporization, were subtracted from the entropies of the saturated vapor to give saturated liquid values. The heats of vaporization were obtained from (*11, 29*). The Bureau of Standards' (*11*) determinations up to 130° C. did not tie in closely with those of Ramsey and Young down to 130° C. (*29*). More weight was assigned to the Bureau of Standards in matching the two curves. The saturation values of entropy are given in Table 1.

As in the entropy calculations, the enthalpy of saturated ethyl alcohol liquid at 32° F. was assigned the value zero. To calculate enthalpies at higher temperatures it was necessary to find the enthalpy of the superheated vapor at zero pressure. To make this preliminary calculation, the enthalpy of the saturated vapor was found by adding to the saturated liquid value the enthalpy of vaporization. To cross the superheated vapor region to zero pressure at the constant temperature of 32° F. the equation,

$$(\partial H/\partial P)_T = V_a - T(\partial V_a/\partial T)_P \qquad (6)$$

was rearranged, using the residual volume, to the following form,

$$(\partial H/\partial P)_T = T(\partial a/\partial T)_P - a \qquad (7)$$

The values of $(\partial a/\partial T)_P$ were taken from the entropy calculations. The entire expression $(T(\partial a/\partial T)_P - a)$ was plotted against pressure and integrated

graphically from the vapor pressure at 32° F. to zero pressure. Once the enthalpy of the alcohol vapor at 32° F. and zero pressure was calculated, it was possible to determine other values at higher temperatures (still at zero pressure) by using the expression,

$$dH^\circ = C_p^\circ dT \qquad (8)$$

To compute enthalpy values at any pressure, Equation (7) was rearranged in a manner similar to the way Equation (3) was rearranged in the entropy calculations. These isothermal calculations gave enthalpy values at each temperature from zero pressure to the vapor pressure.

To smooth the computed results, a cross plot of H vs. T at constant P was constructed. A final plot of enthalpy vs. pressure then was drawn and smoothed values tabulated in Table 2. The saturated vapor enthalpies were read from the final enthalpy-pressure graph at the vapor pressure corresponding to the desired temperature.

Using the same enthalpy of vaporization values as in the entropy calculations and subtracting these from the saturated vapor values, the enthalpy values of the saturated liquid were computed. The saturated values are given in Table 1.

The complete results except for fugacity coefficients are shown graphically on the pressure-enthalpy diagram (Fig. 1).

TABLE 2.—SATURATED SPECIFIC VOLUMES

cu.ft./lb.

Temperature °C.	As Determined by Ramsey & Young and Regnault (29, 30)	As Determined by Bureau of Standards (11)	Residual Volume Calculations
0	482.8	493.6	475.5
10		261.4	255.3
20	144.2	145.2	141.9
30	83.96	83.64	82.42
40	50.76	50.17	49.44
50	31.67	31.14	31.12
60	20.41	19.98	20.06
70	13.49	13.21	13.29
80	9.211	6.970	9.076
90	6.400	6.246	6.297
100	4.569	4.447	4.559
110	3.298	3.234	3.309
120	2.433	2.393	2.431
130	1.826	1.799	1.826
140	1.391		1.395
150	1.076		1.070
160	0.8361		0.833
170	0.6549		0.645
180	0.5142		0.516
190	0.4034		0.399
200	0.3154		0.310
210	0.2446		0.244
220	0.187		0.185
230	0.141		0.142
240	0.0934		0.093
243.1	0.0581		0.063

Discussion of Results

Residual volumes of the saturated vapor were in doubt in some cases because of an insufficient amount of experimental data. The various experimental results as well as those obtained from smoothed curves of residual volume are compared in Table 3. The largest deviations occur at the lower temperatures where both the values cited by Ramsey and Young and Regnault (29, 30) and the Bureau of Standards (11) would yield negative residual volumes. Consequently, the values based upon extrapolation of residual volume curves are believed to be more reliable. The actual measurements of such large volumes at these low temperatures and pressures is difficult.

Saturated vapor enthalpies up to 130° C. were determined by the Bureau of Standards (11), and these values are compared in Table 4 to the enthalpies calculated by the residual volume approach used in this paper. The average absolute deviation was only 0.12%, indicating a high degree of consistency between the spectroscopic data, P-V-T data, and enthalpy measurements of the Bureau of Standards.

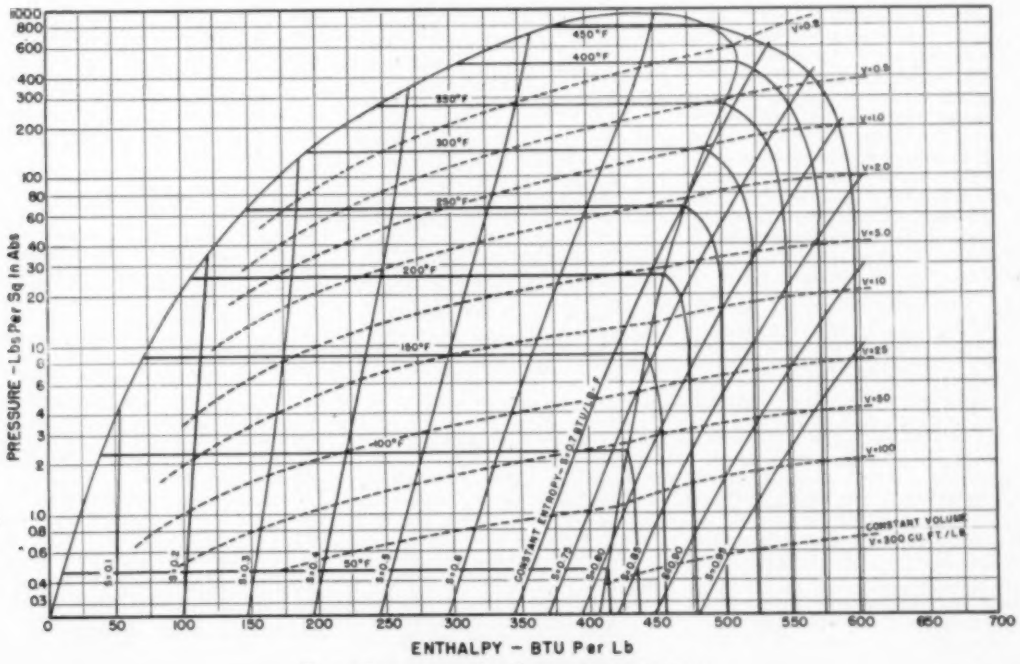

Fig. 1. Pressure-enthalpy diagram for ethyl alcohol.

TABLE 4.—SATURATED VAPOR ENTHALPIES

B.t.u./lb.

Temperature °C.	Bureau of Standards (11)	Calculated from Residual Volume and Spectroscopic Measurements	% Error
0	407.2	407.2	0
10	412.9	412.8	−.02
20	418.4	418.8	+.09
30	423.9	424.6	+.17
40	429.2	429.5	+.07
50	434.5	433.7	−.19
60	440.0	438.6	−.32
70	444.8	446.1	+.29
80	450.0	449.8	−.04
90	455.6	456.0	+.09
100	460.5	461.3	+.17
110	465.8	465.4	−.09
120	471.1	470.7	−.09
130	476.5	476.3	−.04

No entropy values were available for direct comparison with the calculated values. However, by rearranging the basic equation,

$$dH = TdS + VdP$$

to

$$dS = dH/T - V/TdP$$

and integrating along the saturated liquid curve, it was possible to calculate saturated liquid entropies for comparison with the values computed from spectroscopic and P-V-T data. Enthalpy data (*11*) and volumetric data from previous calculations were used. The entropy of the saturated vapor was found at each temperature by adding the entropy change of vaporization to the saturated liquid value. The liquid enthalpies only extended to 130° C., thus the saturated entropy values in excess of this temperature are somewhat in doubt. The comparison shown in Table 5 again indicates good agreement, the average absolute deviation being 0.13%.

The values of $C_p°$ used fitted the spectroscopic values with a maximum error of 0.24% and an average error of 0.05%.

In an over-all consideration of the accuracy of the results, it is believed that the error is less than 1% at the lower temperatures and not greatly exceeding that at the higher temperatures.

Notation

a = residual volume (cu.ft.)/(lb.)
$C_p°$ = heat capacity at constant pressure in the ideal gas state (B.t.u./(lb.mole)(° R.)
f/P = fugacity/pressure ratio (fugacity coefficient)
H = enthalpy of vapor (B.t.u.)/(lb.)
$H°$ = enthalpy of the ideal gas at zero presurse (B.t.u.)/(lb.)
ΔH_v = enthalpy change of vaporization (B.t.u.)/(lb.)
M = molecular weight of ethyl alcohol
P = absolute pressure (lb./sq.in. abs.)
R = gas constant
S = entropy of vapor (B.t.u.)/(lb.)(° R.)
$S°$ = entropy of the ideal gas at unit fugacity (B.t.u.)/(lb.)(° R.)
ΔS_v = entropy change of vaporization (B.t.u.)/(lb.)(° R.)
S_{vp} = entropy of saturated vapor (B.t.u.)/(lb.)(° R.)
T = absolute temperature (° R.)
V_e = experimental specific volume (cu.ft.)/(lb.)
V = specific volume (cu.ft.)/(lb.)

Literature Cited

1. Amagat, E. H., *Ann. chim. phys.* (6), **29**, 505 (1893).
2. Aston, J. G., *Ind. Eng. Chem.*, **34**, 514 (1942).
3. Battelli, A., *R. Mem. accad. sci. Torino*, **40**, 21 (1890); **44**, 57 (1894); **45**, 235 (1895).
4. Bennewitz, K., and Rossner, W., *Z. physik. Chem.*, **B39**, 126 (1938).
5. Blacet, F. E., Leighton, P. A., and Bartlett, E. P., *J. Phys. Chem.*, **35**, 1935 (1931).
6. Bose, E., *Z. phys. chem.*, **58**, 585 (1907).
7. Brickwedde, F. G., Moskow, M., and Aston, J. G., *J. Research Nat. Bur. Standards*, **37**, 263 (1946).
8. Bridgeman, P. W., *Proc. Am. Acad. Arts Sci.*, **49**, No. 1-B (1913).
9. Christensen, L. D., and Smith, J. M., *Ind. Eng. Chem.*, **42**, 2128 (1950).
10. Dixon, H. B., and Greenwood, G., *Proc. Roy. Soc.* (London), **A105**, 199 (1924).
11. Fiock, E. F., Ginnings, D. C., and Helton, W. B., *J. Research Nat. Bur. Standards*, **6**, 881 (1931).
12. Gibson, G. E., Parks, G. S., and Latimer, W. M., *J. Am. Chem. Soc.*, **42**, 1542 (1920).
13. Herz, V. W., *Z. Electrochem.*, **30**, 604 (1924).
14. International Critical Tables, **3**, 27.
15. International Critical Tables, **5**, 114.
16. Jatkar, S. K. K., *J. Indian Inst. Sci.*, **A22**, 39 (1939).
17. Kelley, K. K., *J. Am. Chem. Soc.*, **51**, 779 (1929).
18. Kirejew, V., *Z. Electrochem.*, **35**, 217 (1929).
19. Kolosovaskii, N. A., and Udovenko, V. V., *J. Gen. Chem.* (*U.S.S.R.*), **1**, 255 (1931).
20. Korber, F., *Ann. Physik.* (4), **37**, 1014 (1912).
21. McKelvy, E. C., *Bull. Bur. Standards*, **9**, 436 (1913).
22. Mitsukuri, S., and Hara, K., *Proc. Imp. Acad.* (*Japan*), **5**, 27 (1929).
23. Mock, J. E., and Smith, J. M., *Ind. Eng. Chem.*, **42**, 2125 (1950).
24. Neyreneuf, M., *Ann. chim. phys.* (6), **9**, 535 (1886).
25. Pagliani, S., *Nuovo cimento*, **8**, 157 (1914).
26. Parks, G. S., *J. Am. Chem. Soc.*, **47**, 338 (1925).
27. Parks, G. S., Kelley, K. K., and Huffman, H. M., *J. Am. Chem. Soc.*, **51**, 1969 (1929).
28. Rakovskii, A. V., *Trans. Inst. Pure Chem. Reagents* (*Moscow*), **5**, 5-112R (1927).
29. Ramsey, W., and Young, S., *Phil. Trans. Roy. Soc.* (*London*), **A178**, 314 (1887).
30. Regnault, H. V., *Mém. l'Acad. Sci. Paris*, **26**, 1 (1862).
31. Regnault, H. V., *Ann. chim. phys.* (4), **24**, 342 (1871).
32. Schumann, S. C., and Aston, J. G., *J. Chem. Phys.*, **6**, 480 (1938).
33. Schumann, S. C., Doctoral Dissertation, Pennsylvania State College, 1940; University Microfilms Pub. No. 241 (1941).
34. Seitz, W., and Sechner, G., *Ann. Physik* (4), **49**, 93 (1916).
35. Smith, J. M., *Trans. Am. Inst. Chem. Engrs.*, **42**, 983 (1946).
36. Smith, J. M., *Chem. Eng. Progress*, **44**, 521 (1948).
37. Spencer, H. M., and Flannagan, G. N., *J. Am. Chem. Soc.*, **64**, 2511 (1942).
38. Spencer, H. M., *Ind. Eng. Chem.*, **40**, 2152 (1948).
39. Tammann, G., and Ruhenbeck, A., *Ann. Physik*, **13**, 63 (1932).
40. Tammann, G., and Ruhenbeck, A., *Z. anorg. allgem. Chem.*, **207**, 368 (1932).
41. Tarasenkov, D. N., and Afinogenov, V. P., *J. Phys. Chem.* (*U.S.S.R.*), **9**, 889 (1937).
42. Williams, J. W., and Daniels, F., *J. Am. Chem. Soc.*, **46**, 903 (1924).
43. Young, S., *Sci. Proc. Roy. Dublin Soc.*, **12**, 374 (1910).

TABLE 5.—SATURATED VAPOR ENTROPIES

B.t.u./(lb.mole)(°F.)

Temperature °C.	Calculated from Bureau of Standards (11)	Calculated from Residual Volume and Spectroscopic Measurements	% Error
0	38.15	38.15	0
10	37.33	37.29	−.11
20	36.58	36.54	−.11
30	35.92	35.98	+.17
40	35.31	35.36	+.14
50	34.70	34.71	+.03
60	34.28	34.20	−.23
70	33.82	33.95	+.38
80	33.43	33.47	+.12
90	33.10	33.16	+.18
100	32.80	32.85	+.15
110	32.55	32.54	−.03
120	32.33	32.38	+.15
130	32.16	32.17	+.03

AN EMPIRICAL EQUATION FOR THERMODYNAMIC PROPERTIES OF LIGHT HYDROCARBONS AND THEIR MIXTURES

CONSTANTS FOR TWELVE HYDROCARBONS

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1. Introduction

THE series of papers of which this is a member describes an empirical equation which represents the following classes of thermodynamic properties of light hydrocarbons and their mixtures, in either gaseous or liquid phases:

a. Pressure — volume — temperature — composition data
b. Isothermal change of enthalpy and entropy with pressure
c. Latent heats of vaporization and heats of mixing
d. Fugacities and liquid-vapor equilibria

Use of a single equation to represent these diverse thermodynamic properties has a number of advantages. It provides thermodynamically consistent values of these properties. It facilitates interpolation and extrapolation of experimental data. Calculations involving integration and differentiation, particularly with respect to composition, can be carried out more readily by an equation than by graphical means. Perhaps most important of all, an equation provides a concise summary of a large mass of data, which, in the case of multicomponent mixtures, may be so extensive as to defy complete numerical tabulation or graphical representation.

The first paper of this series (*11*) described the proposed equation and gave numerical values of its eight constants for the pure components methane, ethane, propane, and *n*-butane. The second paper (*12*) showed how the equation might be extended to mixtures of these hydrocarbons. Subsequently (*10*) numerical values of the constants were given for ethylene and isobutane.

The present paper brings together numerical values of the constants for these substances and for the six additional hydrocarbons: propylene, isobutylene, isopentane, *n*-pentane, *n*-hexane, and *n*-heptane. The equation and tabulated values of these constants provide a compact summary of all the thermodynamic properties just listed for any mixture of these hydrocarbons. In this paper, a comparison is made of the properties observed for these individual hydrocarbons with properties indicated by this equation. Organick and Studhalter (*29*) have given values of the constants for benzene, based on experimental measurements of Goronowski, et al (*15*).

The next paper of this series will compare liquid-vapor equilibria observed for mixtures of these hydrocarbons with those predicted by the equation. A final paper will show how the equation may be reduced to a series of charts to facilitate the practical computation of liquid-vapor equilibria in multicomponent systems. The correlation of liquid-vapor equilibria in mixtures of light hydrocarbons has been the primary objective in developing this equation.

2. Description of Equation

2.1 Equation of State. The equation of state used to represent the pressure-volume - temperature - composition relations of gaseous and liquid mixtures in this series of papers is:

$$P = RTd + (B_o RT - A_o - C_o/T^2)d^2 + (bRT - a)d^3 + ad^6 + \frac{cd^3}{T^2}[(1 + \gamma d^2)e^{-\gamma d^2}] \qquad (1)$$

In this equation, P is the absolute pressure, T is the absolute temperature, d is the molal density, and R is the universal gas constant, in consistent units. The eight parameters B_o, A_o, C_o, b, a, c, α, and γ are numerical constants for pure substances and functions of composition for mixtures. In the present state of knowledge regarding thermodynamic properties of hydrocarbon mixtures, the dependence of these parameters on mole fractions, x_i, may be represented by the equations:

$$B_o = \left[\sum_i x_i B_{oi}\right] \qquad (2)$$

$$A_o = \left[\sum_i (x_i A_{oi}^{1/2})\right]^2 \qquad (3)$$

$$C_o = \left[\sum_i (x_i C_{oi}^{1/2})\right]^2 \qquad (4)$$

$$b = \left[\sum_i (x_i b_i^{1/3})\right]^3 \qquad (5)$$

$$a = \left[\sum_i (x_i a_i^{1/3})\right]^3 \qquad (6)$$

$$c = \left[\sum_i (x_i c_i^{1/3})\right]^3 \qquad (7)$$

$$\alpha = \left[\sum_i (x_i a_i^{1/3})\right]^3 \qquad (8)$$

$$\gamma = \left[\sum_i (x_i \gamma_i^{1/2})\right]^2 \qquad (9)$$

In these equations, symbols with the suffix i, such as B_{oi}, b_i, etc., are numerical constants for the ith pure component, with values given in Tables 1 and 2. Thus, by means of these equations, the equation of state for mixtures (1) may be derived from data on pure components alone, without the need for supplementary data on mixtures. As data on mixtures are accumulated, however, it is anticipated that representations of the dependence of the parameters on composition that are more accurate than Equations (2)-(9) will be developed. The second paper of this series (*12*) gives the general functional form this composition dependence must take.

A word of explanation is necessary regarding the choice of density and temperature as independent variables in equation of state (1), instead of pressure and temperature, as would be more convenient for engineering applications. In order to represent the properties of mixtures at high pressures, it is necessary to use an equation of state which will summarize the properties of the gas phase, the liquid phase, and the critical phase between them in a single formula. Since the gas phase and liquid phase of a pure substance in equilibrium have different densities at the same pressure and temperature, choice of pressure and temperature as independent variables would

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have led to a multiple-valued function for the density, which could not be represented by simple functions without singularities. This difficulty does not arise when the pressure is expressed as a function of density and temperature, as in (1). It is noteworthy that all equations of state that have been applicable to a wide range of conditions, such as the Van der Waals (*38*), Beattie-Bridgeman (*3*), and Redlich (*30*) equations, express the pressure as a function of density and temperature.

2.2 Fundamental Equation. Gibbs (*14*) has termed a fundamental equation any relation between independent thermodynamic variables from which all other thermodynamic properties may be obtained by purely mathematical operations. Equation of state (1) is not a fundamental equation in this sense, because to obtain such other properties as enthalpies, entropies or fugacities from it requires a knowledge of integration constants not contained in the equation of state itself. When the independent variables are density and temperature, Gibbs (*14*) has shown that the only thermodynamic function which gives a fundamental equation is the work content, A. This function is also shown as the Helmholtz free energy or the Gibbs ψ-function; it is related to the energy, E, and entropy, S, by:

$$A = E - TS \qquad (10)$$

In these papers A, E, and S refer to one mole of mixture.

Statistical mechanics establishes that a fundamental equation for the work content of a gaseous mixture may be obtained from the equation of state by the relation:

$$A = \sum x_i[RT \ln dRTx_i + E^\circ_i - TS^\circ_i] + \int_o^d \frac{P - RTd}{d^2}\,\delta d \qquad (11)$$

The summation term of this equation represents the work content of an ideal gas mixture at the density, temperature and composition of the actual mixture; E°_i and S°_i are, respectively, the energy and entropy of one mole of the ith pure component in the ideal gas state at unit pressure. The integral represents the difference between the work content of the actual mixture and that of an ideal gas; it is known as the residual work content. The value of this formulation is that it segregates the work content into two parts, one obtainable from the properties of the pure components in the ideal gas state, and the other from the equation of state of the actual mixture.

The fundamental equation for gas mixtures obtainable by substituting equation of state (1) in (11) is:

$$A = \sum x_i[RT \ln dRTx_i + E^\circ_i - TS^\circ_i] + (B_oRT - A_o - C_o/T^2)d + (bRT - a)d^2/2 + \alpha ad^5/5 + \frac{cd^2}{T^2}\left[\frac{1 - exp(-\gamma d^2)}{\gamma d^2} - \frac{exp(-\gamma d^2)}{2}\right] \qquad (12)$$

To complete the formulation of the thermodynamic properties of liquids as well as gases, the assumption is made that Equation (12) holds for liquid mixtures, also. This assumption is checked by the comparison between liquid-vapor equilibria predicted by fugacities evaluated from (12) and observed liquid-vapor equilibria in hydrocarbon mixtures, to be reported in the next paper of this series.

2.3 Fugacities. The fugacity, f_i, is obtained from the work content by the thermodynamic relation:

$$RT \ln f_i = (\partial NA/\partial n_i)_{V,T,n} - [E^\circ_i - TS^\circ_i + RT] \qquad (13)$$

where n_i = number of moles of ith component, and N = total number of moles $= \sum n_i$. An equation for the fugacity is obtained by applying this relation to fundamental Equation (12) and Equations (*2*)-(9):

$$RT \ln f_i = RT \ln dRTx_i + [(B_o + B_{oi})RT - 2(A_oA_{oi})^{1/2} - 2(C_oC_{oi})^{1/2}/T^2]d + 3/2[RT(b^2b_i)^{1/3} - (a^2a_i)^{1/3}]d^2 + 3/5[a(a^2a_i)^{1/3} + \alpha(a^2a_i)^{1/3}]d^5 + \frac{3d^2(c^2c_i)^{1/3}}{T^2}\left[\frac{1 - exp(-\gamma d^2)}{\gamma d^2} - \frac{exp(-\gamma d^2)}{2}\right] - \frac{2d^2c}{T^2}\left(\frac{\gamma_i}{\gamma}\right)^{1/2}\left[\frac{1 - exp(-\gamma d^2)}{\gamma d^2} - exp(-\gamma d^2) - \frac{\gamma d^2 exp(-\gamma d^2)}{2}\right] \qquad (14)$$

It is noteworthy that the equation for the fugacity does not contain E_i° or S_i°, and involves only the parameters of the equation of state, B_o, A_o, etc. Thus, a knowledge of these parameters is sufficient to predict fugacities, and from them liquid-vapor equilibria.

2.4 Other Thermodynamic Functions. The entropy, energy and enthalpy may be obtained from fundamental Equation (11) by the thermodynamic relations:

$$S = -(\partial A/\partial T)_{d,n}\,* \qquad (15)$$

$$E = A + TS \qquad (16)$$

$$H = E + P/d \qquad (17)$$

Thus:

Entropy:
$$S = \sum x_i[S_i^\circ - R \ln dRTx_i] - (B_oR + 2C_o/T^3)d - bRd^2/2 + \frac{2cd^2}{T^3}\left[\frac{1 - exp(-\gamma d^2)}{\gamma d^2} - \frac{exp(-\gamma d^2)}{2}\right] \qquad (18)$$

Energy:
$$E = \sum x_iE_i^\circ - (A_o + 3C_o/T^2)d - ad^2/2 + \alpha ad^5/5 + \frac{3cd^2}{T^2}\left[\frac{1 - exp(-\gamma d^2)}{\gamma d^2} - \frac{exp(-\gamma d^2)}{2}\right] \qquad (19)$$

Enthalpy:
$$H = \sum x_iH_i^\circ + (B_oRT - 2A_o - 4C_o/T^2)d + (2bRT - 3a)d^2/2 + 6\alpha ad^5/5 + \frac{cd^2}{T^2}\left[3\frac{1 - exp(-\gamma d^2)}{\gamma d^2} - \frac{exp(-\gamma d^2)}{2} + \gamma d^2 exp(-\gamma d^2)\right] \qquad (20)$$

The properties S_i°, E_i°, and H_i° of the pure components in the ideal gas state at unit pressure are evaluated from calorimetric data by means of the third law of thermodynamics or from molecular spectra by statistical mechanics. Values of these properties for the hydrocarbons discussed in this series of papers are given in tables issued by the Bureau of Standards (*2*).

3. Values of Constants

Table 1 lists values of the eight constants B_o, A_o, C_o, b, a, c, γ and α for twelve hydrocarbons, expressed in metric units. The bottom half of this table gives the fractional powers of these constants entering Equations (*2*)-(9) for mixtures. Table 2 lists similar data expressed in English engineering units.

The molecular weights and values of T_o and R to be used with these constants are 1937 values, because of the precedent set at the time this work was started.

It is, of course, impossible to assign unique values accurate to six significant figures to each of these parameters.

* In using this equation, note that $\left(\frac{\partial E_i^\circ}{\partial T}\right)_d - T\left(\frac{\partial S_i^\circ}{\partial T}\right)_d = C_{vi}^\circ - C_{vi}^\circ = -R$

TABLE 1

CONSTANTS FOR INDIVIDUAL HYDROCARBONS

Units: P = normal atmospheres
d = gm. moles/liter
T = degrees Kelvin (°C. + 273.13)
R = 0.08207 (liter)(atm.)/(gm. mole)(°K)

METRIC UNITS

Substance	Methane	Ethylene	Ethane	Propylene	Propane	i-Butane	i-Butylene	n-Butane	i-Pentane	n-Pentane	n-Hexane	n-Heptane
Molecular Wt.	16.031	28.031	30.047	42.047	44.062	58.078	56.062	58.078	72.094	72.094	86.109	100.125
B_0	0.0426000	0.0956833	0.0827724	0.0850947	0.0973130	0.137344	0.116625	0.124361	0.160053	0.156751	0.177813	0.199805
A_0	1.85500	3.33958	4.15556	6.11220	6.87225	10.23264	8.95325	10.0847	12.7959	12.1754	14.4373	17.5206
$C_0 \times 10^{-6}$	0.0229700	0.131140	0.179598	0.439182	0.908256	0.869943	0.927280	0.992830	1.74632	2.12121	3.31935	4.74574
b	0.00338004	0.0086000	0.0111220	0.0187059	0.0225000	0.0424352	0.0348156	0.0399983	0.0668120	0.0668120	0.1091.31	0.1519.54
a	0.494000	0.259000	0.345160	0.774096	0.947700	1.97863	1.69270	1.98231	3.75620	4.07480	7.11671	10.36475
$c \times 10^{-6}$	0.00256500	0.0221120	0.0327670	0.102611	0.129000	0.286010	0.274920	0.326400	0.695000	0.804170	1.51276	2.47000
$\alpha \times 10^{3}$	0.124359	0.178000	0.243389	0.456696	0.607175	1.07408	0.910889	1.10132	1.70000	1.81000	2.81086	4.35611
$\gamma \times 10^{2}$	0.60000	0.923000	1.18000	1.82900	2.20000	3.40000	2.95945	3.40000	4.63000	4.75000	6.66849	9.00000
$A_0^{1/2}$	1.36198	1.82745	2.03852	2.47229	2.62150	3.19885	2.99220	3.17564	3.57716	3.48990	3.79964	4.18576
$C_0^{1/2} \times 10^{-3}$	0.150233	0.362133	0.423783	0.662708	0.712921	0.921924	0.962954	0.996410	1.32148	1.45644	1.82178	2.17647
$b^{1/3}$	0.150075	0.204880	0.223217	0.265456	0.282310	0.348799	0.326531	0.341990	0.405775	0.405775	0.477876	0.533626
$a^{1/3}$	0.366924	0.637431	0.701466	0.918172	0.982254	1.24669	1.19178	1.23471	1.55447	1.59723	1.92350	2.18032
$c^{1/3} \times 10^{-2}$	0.136530	0.278417	0.319997	0.468164	0.505277	0.658881	0.650233	0.681435	0.885705	0.937574	1.14795	1.35176
$\alpha^{1/3} \times 10$	0.497843	0.562523	0.624358	0.769531	0.846781	1.02411	0.969368	1.03269	1.19368	1.21869	1.41128	1.63318
$\gamma^{1/2} \times 10$	0.774600	0.960729	1.08628	1.35241	1.48324	1.84391	1.72031	1.84391	2.15174	2.17965	2.58234	3.00000

Nevertheless, the full six figures given in these tables should be used in calculating the properties of liquids, and four or five should be used for gases. A change of one in the sixth place of one constant by itself will alter the calculated pressure of a liquid by about 0.01 atm. However, it is possible to change all the constants simultaneously by about 5 per cent without seriously prejudicing the calculated results. This point should be borne in mind in any attempted correlation of the constants with other properties of the hydrocarbons.

4. Comparison of Properties of Pure Hydrocarbons

The first paper of this series (*11*) described the general procedure used in fitting the equation of state to properties of individual hydrocarbons. Principal weight was given to P-V-T data, critical properties and vapor pressures above one atmosphere. Table 3 presents a summarized comparison between the predictions of the equation and observations of each of these three properties. References are given to the sources of data used for each hydrocarbon, and the ranges of conditions over which the equation was fitted are shown.

The calculated critical density and temperature are the values at which

$$\left(\frac{\partial P}{\partial d}\right)_T = 0$$

and

$$\left(\frac{\partial^2 P}{\partial d^2}\right)_T = 0$$

The calculated critical pressure is the pressure at this point calculated by the equation of state (1).

The calculated vapor pressure at a given temperature is obtained by finding

TABLE 2

CONSTANTS FOR INDIVIDUAL HYDROCARBONS

Units: P = lbs./sq. in. absolute
d = lb. moles/cu.ft.
T = degrees Rankine (°F. + 459.63)
R = 10.7335 (lbs.)(ft.)^3/(in.)^2(lb. mole)(°R)

ENGLISH UNITS

Substance	Methane	Ethylene	Ethane	Propylene	Propane	i-Butane	i-Butylene	n-Butane	i-Pentane	n-Pentane	n-Hexane	n-Heptane
Molecular Wt.	16.031	28.031	30.047	42.047	44.062	58.078	56.062	58.078	72.094	72.094	86.109	100.125
B_0	0.682401	0.891980	1.00554	1.36263	1.55884	2.20329	1.85858	1.99211	2.56386	2.51096	2.84835	3.18782
A_0	6995.25	12593.6	15670.7	23049.2	25915.4	38587.4	33762.9	38029.6	4825.36	45928.8	5443.6	66070.6
$C_0 \times 10^{-6}$	275.763	1602.28	2194.27	5365.97	6209.93	10344.7	11329.6	12130.5	21338.7	25917.2	40556.2	57984.0
b	0.867325	2.20678	2.85393	4.79997	5.77355	10.8890	8.93375	10.2836	17.1461	17.1461	28.0032	38.9917
a	2986.12	15665.5	20890.2	46756.6	57268.0	119647.	102291.	119705.	228908.	246148.	429901.	626106.
$c \times 10^{-6}$	498.106	4133.60	6413.14	20083.0	25247.8	55977.7	53807.2	61925.6	136029.	161308.	296077.	483477.
$\alpha \times 10^{3}$	511.172	731.661	1000.44	1873.12	2495.77	4414.96	3744.17	4526.93	6987.77	7439.92	11552.9	17905.6
$\gamma \times 10^{2}$	153.961	236.814	302.790	469.325	564.524	872.447	759.401	872.447	1188.07	1218.86	1711.15	2309.42
$A_0^{1/2}$	83.6376	112.221	125.183	151.820	160.983	196.437	183.747	195.012	219.667	214.310	233.331	257.042
$C_0^{1/2} \times 10^{-3}$	16.6061	40.0285	46.8430	73.2538	78.8031	101.705	106.441	110.139	146.071	160.988	201.386	240.799
$b^{1/3}$	0.953644	1.30193	1.41845	1.68686	1.79396	2.21647	2.07497	2.17320	2.57853	2.57853	3.03671	3.39097
$a^{1/3}$	14.3970	25.0109	27.5235	36.0286	38.5408	48.9165	46.7620	48.4664	60.9929	62.6707	75.4726	85.5494
$c^{1/3} \times 10^{-2}$	7.92684	16.0486	18.5788	27.1813	29.3360	38.2530	37.7521	39.5625	51.4281	54.4349	66.6492	78.4822
$\alpha^{1/3} \times 10$	7.99567	9.01096	10.0315	12.3270	13.5644	16.4050	15.5281	16.5425	19.1181	19.5220	22.6070	26.1616
$\gamma^{1/2} \times 10$	12.4082	15.3897	17.4009	21.6640	23.7597	29.5372	27.5573	29.5372	34.4683	34.9102	41.3660	48.0984

TABLE 3

SUMMARIZED COMPARISON OF OBSERVED PROPERTIES OF LIGHT HYDROCARBONS WITH THOSE PREDICTED BY EQUATION

	Methane	Ethylene	Ethane	Propylene	Propane	Isobutane	Isobutylene	n-Butane	Isopentane	n-Pentane	n-Hexane	n-Heptane	General Average
1. Pressures of Gaseous Phase													
Ave. % Deviation of Pressures	0.34	0.42	0.31	0.24	0.60	0.90	0.39	0.31	0.62	0.56	0.74	0.68	0.46
Range of Density, moles/liter													
From	0	0	0.5	0.5	1	0.5	1	0.5	0.5	0.66	2.5	1	-
To	18	12.8	10	8	9	9	7	7	7	6.8	5	4	-
Range of Temperature, °C.													
From	-90	0	25	25	96.8	104.4	150	150	150	140	225	275	-
To	200	196.8	275	300	275	237.8	275	300	300	300	275	300	-
Sources	(23),(24)	(1),(25)	(4),(9)	(39)	(4)	(22)	(5)	(8)	(41)	(31),(33)	(10)	(37)	
2. Deviation of Critical Properties, Obs. - Calc.													
Pressure, atm.	-1.5	-0.39	-0.17	-0.7	-0.42	-0.28	0.67	-0.05	-0.03	+0.88	-0.48	-0.28	0.46
Temperature, °C.	-0.3	-0.39	-0.25	-0.7	-0.16	±0.28	0.7	-0.04	-0.3	+1.6	+0.4	-0.83	0.47
Density, mol./liter	+0.06	-0.2	+0.08	-0.15	±0.0	±0.15	± 0.0	+0.13	+0.29	+0.34	+0.17	+0.38	0.18
Sources	(22)	(26)	(9),(39)	(39)	(7)	(21)	(5)	(8)	(41)	(40),(33)	(40)	(37)	
3. Properties of Saturated Liquid													
Ave. % Deviations of Densities	0.7	1.4	2.7	3	2.3	----	--	1.3	3	3	3	3	2.3
Ave. % Deviation of Vapor Pressures	2.4	2.4	0.4	3	1.0	1.3	2.8	0.7	3	3	3	3	2.1
Range of Vapor Pressure, atm.													
From	4.5	2.1	1.5	2.1	1.0	1.0	1.0	1.0	0.34	2.1	1.0	1.0	-
To	41.8	31.9	41.4	26.9	28.0	27.2	27.2	22.5	21.7	20.5	13.8	13.6	-
Range of Temperature, °C.													
From	-160	-90	-90	-30	-25	-12	-7	4	0	60	70	100	-
To	- 85	-10	25	90	75	119	120	131	146	196	220	221	-
Sources	(32)	(27)	(1),(27)	(18)	(7),(34),(13)	(13),(18),(38)	(25),(5),(27)	(13),(8),(36)	(11)	(40)	(40)	(38),(16)	

TABLE 4

VALUES OF C_o ADJUSTED TO AGREE WITH OBSERVED VAPOR PRESSURES

Temperature, °F.	-100	-40	0	50	100
Temperature, °C.	-73.33	-43.34	-17.78	10.00	37.78
Component	$C_o \cdot 10^{-6}$				
Ethane	0.1704491				
Propylene	0.4274475	0.4337777			
Propane	0.4689205	0.4995288			
i-Butane	0.8200652	0.8345318	0.8665489		
1-Butylene	0.8733559	0.8955548	0.9113561		
n-Butane	0.9346083	0.9590029	0.9771238		
i-Pentane		1.0.9956	1.72882	1.74993	
n-Pentane		2.02656	2.04683	2.09523	2.10854
n-Hexane			3.18382	3.24078	3.28779
n-Heptane			4.68276	4.59766	4.67583
	Vapor Pressure - Atmospheres				
Ethane	2.128				
Propylene	0.862	1.099			
Propane	0.19646	0.25483			
i-Butane	0.03737	0.21219	0.78371		
1-Butylene	0.02729	0.1677	0.6508		
n-Butane	0.01866	0.12145	0.49309		
i-Pentane		0.0706	0.1478	0.4905	
n-Pentane		0.01854	0.10046	0.3760	1.066
n-Hexane			0.02136	0.09868	0.3267
n-Heptane			0.005079	0.02697	0.1103

the vapor density d^G and liquid density d^L at which the fugacity of the gas and liquid phases are equal:

$$RT \ln f(d^G,T) = RT \ln f(d^L,T)$$

and the pressure of both phases are equal:

$$P(d^G,T) = P(d^L,T)$$

The pressure given by the latter equation is the calculated vapor pressure.

As Table 3 shows, satisfactory agreement is obtained between gas phase pressures, critical properties and vapor pressures observed for these hydrocarbons and those predicted by the equation. At densities up to 1.8 times the critical density, the average absolute deviation of gas phase pressures predicted by the equation of state is 0.46%; for most hydrocarbons, the average deviation is less than 0.5%. The average absolute deviations of critical properties are 0.48 atm. for pressure, 0.47° C. for temperature, and 0.18 g.moles/l. for density. The average absolute deviation of superatmospheric vapor pressures is 2.1%.

Because of the good fit with *P-V-T* data, the constants of the equation may be used in Equation (18), (19) or (20) to evaluate the difference between the entropy, energy, or enthalpy of an actual gas and that of an ideal gas, with accuracy satisfactory for engineering calculations. Close correspondence between observed enthalpy differences and those predicted by Equation (20) have been demonstrated for methane (*11*) and benzene (*29*).

The close correspondence between predicted and observed properties of these hydrocarbons makes the equation, with the constants of Tables 1 and 2, a satisfactory means of summarizing these diverse properties within the range of variables to which the equation has been fitted.

Extrapolation to higher temperatures or lower densities than those to which the equation has been fitted may be carried out with reasonable accuracy, because deviations from the ideal gas laws then become smaller. Extrapolation to higher densities or lower temperatures will lead to serious error.

5. Subatmospheric Vapor Pressures

In correlating data on liquid-vapor equilibria, it is often necessary to work at temperatures at which vapor pressures of some components are below one atmosphere. Since a substantial error in vapor pressures predicted by the equation with the constants of Tables 1 and 2 is made in this range, it would be expected that fugacities in mixtures evaluated at such temperatures would also be in error. It is therefore important to devise a means for representing subatmospheric vapor pressures accurately by means of the equation. This has been done by adjusting the constant C_o at temperatures corresponding to subatmospheric vapor pressures, so that agreement with observed vapor pressures is obtained.

Table 4 lists values of C_o adjusted to obtain agreement with vapor pressures at temperatures below the ranges given in Table 3. Values selected for individual vapor pressures are also given.

Literature Cited

1. Amagat, E. H., *Ann. chimie et phys.*, **29**, 68 (1893).
2. American Petroleum Institute. Research Project No. 44 at the Nat. Bur. Standards. Selected Properties of Hydrocarbons.
3. Beattie, J. A., and Bridgeman, O. C., *Proc. Am. Acad. Arts Sci.*, **63**, 229 (1928).
4. Beattie, J. A., Hadlock, C., and Poffenberger. N., *J. Chem. Phys.*, **3**, 93 (1935).
5. Beattie, J. A., Ingersoll, H. G., and Stockmayer, W. H., *J. Am. Chem. Soc.*, **64**, 546, 548 (1942).
6. Beattie, J. A., Kay, W., and Kaminsky, J., *J. Am. Chem. Soc.*, **59**, 1589 (1937).
7. Beattie, J. A., Poffenberger, N., and Hadlock, C., *J. Chem. Phys.*, **3**, 96 (1935).
8. Beattie, J. A., Simard, G. L., and Su, G.-J., *J. Am. Chem. Soc.*, **61**, 24, 26 (1939).
9. Beattie, J. A., Su, G.-J., and Simard, G. L., *J. Am. Chem. Soc.*, **61**, 924, 926 (1939).
10. Benedict, M., Solomon, E., and Rubin, L. C., *Ind. Eng. Chem.*, **37**, 55 (1945).
11. Benedict, M., Webb, G. B., and Rubin. L. C., *J. Chem. Phys.*, **8**, 334 (1940).
12. Benedict, M., Webb, G. B., and Rubin, L. C., *Ibid.*, **10**, 747 (1942).
13. Dana, L. I., Jenkins, A. C., Burdick, J. N., and Timm, R. C., *Refrig. Eng.*, **12**, 387 (1926).
14. Gibbs, J. W., "Collected Works," Longmans, Green and Co., New York (1931).
15. Goronowski, E. J., Amick, E. H., and Hixson, A. N., *Ind. Eng. Chem.*, **39**, 1348 (1947).
16. International Critical Tables, **3**, 224.
17. International Critical Tables, **3**, 230.
18. International Critical Tables, **3**, 244.
19. Kelso, E. A., and Felsing, W. A., *J. Am. Chem. Soc.*, **62**, 3132 (1940).
20. Kay, W. B., *Ind. Eng. Chem.*, **30**, 459 (1938).
21. M. W. Kellogg Co., Unpublished Data.
22. Keyes, F. G., Taylor, R. S., and Smith, L. B., *J. Math. Phys.* (M.I.T.), **1**, 211 (1922).
23. Kvalnes, H. M., and Gaddy, V. L., *J. Am. Chem. Soc.*, **53**, 394 (1931).
24. Maass, O., and Gedes, A. L., *Phil. Trans. Roy. Soc.*, **A236**, 303 (1937).
25. Michels, A., DeGruyter, J., and Niesen, F., *Physica*, **3**, No. 5, 347 (1936).
26. Michels, A., and Nederbragt, G. W., *Physica*, **3**, 569 (1936).
27. Morehouse, F. R., and Maass, O., *Can. J. Research*, **11**, 637 (1934).
28. Morris, W. M., Sage, B. H., and Lacey, W. M., *Am. Inst. Mining Met. Engrs.*, Tech. Pub., No. 1128 (1939).
29. Organick, E. I., and Studhalter, W. R., *Chem. Eng. Progress*, **44**, 847 (1948).
30. Redlich, O., and Kwong, J. N. S., *Chem. Rev.*, **44**, 233 (1949).
31. Rose-Innes, J., and Young, S., *Phil. Mag.* (Edinburgh) Series 5, **47**, 353 (1899).
32. Sage, B. H., and Lacey, W. N., *Ind. Eng. Chem.*, **30**, 673 (1938).
33. Sage, B. H., and Lacey, W. N., *Ind. Eng. Chem.*, **34**, 730 (1942).
34. Sage, B. H., Schaafsma, J. G., and Lacey, W. N., *Ind. Eng. Chem.*, **26**, 1218 (1934).
35. Sage, B. H., Webster, D. C., and Lacey, W. N., *Ind. Eng. Chem.*, **29**, 685 (1937).
36. Sage, B. H., Webster, D. C., and Lacey, W. N., *Ind. Eng. Chem.*, **29**, 1188 (1937).
37. Smith, L. B., Beattie, J. A., and Kay, W., *J. Am. Chem. Soc.*, **59**, 1587 (1937).
38. Van der Waals, J., "Die Continuität des Gasformigen und Flüssigen Zustandes," Barth, Leipzig (1899).
39. Vaughan, W. E., and Graves, N. R., *Ind. Eng. Chem.*, **32**, 1252 (1940).
40. Young, S., *Proc. Roy. Irish Acad.*, **38B**, No. 5, 65 (1928).
41. Young, S., *Proc. Phys. Soc.* (*London*), **13**, 602 (1894-1895).

LIMITING FLOWS IN PACKED EXTRACTION COLUMNS

Correlation for Large Packings

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Data are reported for limiting flows of various liquids in a 12-in. diameter tower packed with one-half in., one in., and one and one-half in. carbon Raschig rings. A new correlation is presented which fits available data for columns packed with rings of one-fourth in. to one and one-half in. nominal diameter and one-half in. Berl saddles and clay spheres.

LIQUID-liquid extraction in packed columns ordinarily involves countercurrent flow of two immiscible liquid phases through the packing. Flow occurs as a result of gravitational forces due to a difference in density between the two phases. One phase, denoted as the "continuous phase," fills the voids in the packing and flows through the column in a continuous manner. The second phase, "discontinuous phase," is subdivided into small globules by a suitable distributor and passes through the continuous phase and the interstices of the packing in the form of individual globules or droplets. Either phase may be made discontinuous by proper distributor design and location.

For a given flow rate of one phase in a given column there will be some maxium flow rate of the other phase, which if exceeded will result in accumulation of one of the phases in the column and cause ultimate failure of column operation. This limiting flow condition, or flooding point, is a function of the particular liquid system and packing under consideration.

A correlation of limiting flows has been presented by Breckenfeld and Wilke (*3*) based on their data for ¼-in. Raschig rings and the data of Blanding and Elgin (*2*) on various ½-in. packings. Ballard and Piret (*1*) investigated limiting flow phenomena in ¼-in. and ½-in. packings and interpreted the results in terms of a "transition point" defined for operation of the liquid which preferentially wets the packing as the continuous phase, beyond which rates the column may flood or else change the flow mechanism to accommodate higher rates. Elgin and Faust (*4*) have studied limiting flows in countercurrent flow of solid particles through moving fluids and present data and correlations which may prove of interest to the present subject. The work of Hayworth and Treybal (*5*) on drop formation in two-liquid systems likewise may be of interest.

In view of the absence of flooding data on large packings in the literature, and the desirability of testing previous correlations under more extended conditions, the present study was undertaken.

Experimental

Apparatus. The design of the column was based upon a smaller one operated previously by Breckenfeld and Wilke (*3*). The column was built in three sections of 12-gauge sheet steel welded at the joints and galvanized after fabrication. It was assembled by means of flanges and neoprene gaskets as shown in Figures 1 and 2.

The main section was 12 in. I.D. and 46 in. in length. Following the type described by Blanding and Elgin (*2*), an expanding section 12 in. long and tapering from 24 in. to 12 in. in diameter was welded to the bottom of the main section. The packing

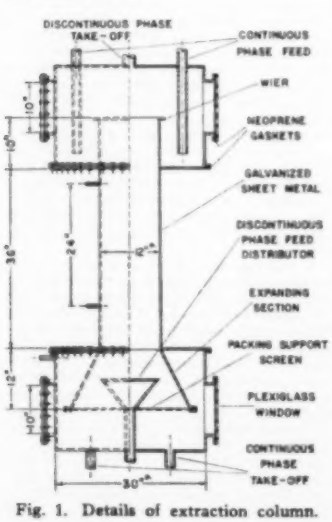

Fig. 1. Details of extraction column.

Fig. 2. The extraction column.

* Present address: Proctor and Gamble Co., St. Louis, Mo.

TABLE 1 PACKING CHARACTERISTICS

Series		a sq. ft. cu. ft.	Drain Void Fraction	F Dry Void Fraction
A	1/2" Carbon Raschig Rings	131.	0.700	0.707
B	1-1/2" Carbon Raschig Rings	34.2	0.672	0.679
C	1" Carbon Raschig Rings	59.4	0.733	0.740
D	1" Carbon Raschig Rings	60.7	0.727	0.734
E	1" Carbon Raschig Rings	62.0	0.721	0.728
F	1" Carbon Raschig Rings	63.3	0.715	0.722
1-7	1/4" Carbon Raschig Rings[3]	208.		0.534
8	1/2" Porcelain Berl Saddles[3]	120.*		0.695
9-12	1/2" Porcelain Berl Saddles[a]	110.		0.75
13-14	1/2" Carbon Raschig Rings[a]	114.		0.74
15-16	1/2" Clay Spheres[a]	72.		0.50

*Based on manufacturer's data

support, galvanized wire mesh, was held in place by a brass collar bolted to a flange on the bottom of the expanded section. In view of observations (*2, 3*) that location of the packing support above the distributor leads either to unsatisfactory operation or to reduced flow rates, no other packing support location was used.

The top and bottom sections were 20 in. in height and of 30 in. I.D. Two 10-in.-square windows were provided directly opposite each other on each section. The windows were constructed of ⅜-in. Plexiglas with neoprene used as a gasket material between the plastic and the supporting flange.

The continuous phase was introduced through two 1½-in. pipes extending into the annular space between the top section and the top of the main section. With this arrangement, the top of the main section acted as weir over which the continuous phase flowed, giving no interference with the rising drops of the discontinuous phase. The discontinuous phase was taken off through a 2-in. fitting at the center of the top section.

The discontinuous phase distributor consisted of a funnel 6 in. long tapering from the outside of the 1½-in. feed pipe to 12 in. in diameter at the discharge end. The top of the distributor was a brass plate with holes equally spaced on equilateral triangular centers over its area. Two plates were used, drilled with 92 holes of $^{9}/_{64}$-in. and ¼-in. diameter respectively.

Two 18-in. differential manometers were connected as shown in Figure 3, one across a straight 2-ft. section of packing and the other effectively across the lower expanding section. These were used to estimate column holdup and to indicate when the column had returned to equilibrium after a change in flow rates.

Equipment Layout and Flow. A schematic diagram of the column and related equipment is shown in Figure 3. Because of the relatively large volumes of liquids handled, the system was operated closed to the atmosphere with two 55-gal. stainless steel barrels used as reservoir tanks for the two phases. The top disengaging section was of such a size that control of the level of the liquid interface was automatic, and the swiveled "U" arm usually used to control the height of the liquid interface in laboratory columns was eliminated. At all times, the liquid interface was visible on the surface of the top windows.

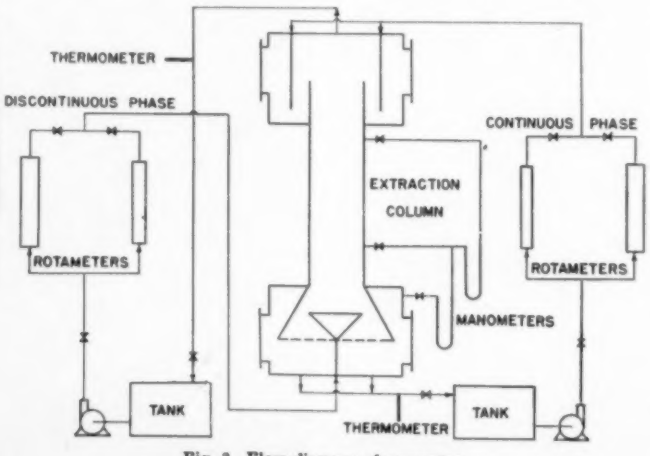

Fig. 3. Flow diagram of apparatus.

The two liquids were circulated with centrifugal pumps, and 1½-in. standard galvanized pipe was used throughout with the exception of a short section of 2-in. pipe fitted at the top of the tower for the light phase take-off. The flow rates of the two phases were measured with rotameters calibrated in place with each of the liquids used. A 5-gal./min. and a 50-gal./min. rotameter were used in each liquid line for accurate measurements at both high and low flow rates. Good control of flow rates at all ranges was obtained with globe valves in each rotameter line.

Packing Materials. Three different packing materials were used: ½, 1, and 1½-in. carbon Raschig rings manufactured by the National Carbon Co. Before packing the column, the packing was sorted for removal of all irregular and broken pieces. The column was packed to the top—a height of 46 in.—by wet dumping with the column filled with water.

Since one of the phases in all cases was aqueous, water was used to flush out the packing between runs; and it was not necessary to repack the column upon changing the liquid systems. Several systems were investigated consecutively with 1-in. rings, and a drop in the height of the packing of about 1 in. was observed after each series. The drain voids were measured by means of two small pipe taps located 2 ft. apart on the extraction column. With the packed section first filled with water, the upper valve was opened and the water drained down to the level of the upper valve. Then the lower valve was opened, and the water drained from the measured space between the valves was collected and weighed to determine the drain void fraction of the packing.

The surface area of the Raschig rings was calculated from average measured dimensions of 200 rings of each size selected at random. The number of rings per cubic foot was determined by counting the number of rings required to pack two linear feet. On the basis of these measurements, packing characteristics were calculated for the column as packed as listed in Table 1, Series *A* through *F*.

Liquid Materials. To establish the general effect of packing properties on capacity the system water (continuous)—gasoline (discontinuous) was studied in each packing. The gasoline was a heavy low sulfur straight run distillate with Engler distillation end point of approximately 400° F. A solution of approximately 56% glycerol in water was operated as both the continuous and discontinuous phase to study the effect of relatively high viscosity. Carbon tetrachloride was used as a continuous phase to obtain runs with a large density difference between the phases. The systems and properties of the liquids used are given in Table 2.

Liquid properties of each phase were measured in a constant temperature bath at 25° C. on samples taken during each series. Densities were measured with a Westphal balance, and interfacial tension was measured using the drop weight-volume method described by Harkins (*9*). An Ostwald viscometer was used to measure viscosities of all materials. Liquid temperatures during each run were measured with mercury-in-glass thermometers located in both phase exit lines from the tower. The range of temperatures encountered, 22 to 32° C., was not large; and liquid properties were corrected from the measured values at 25° C. to the temperature at each flooding point. In the final correlation an average temper-

ature was calculated for each series and the fluid properties evaluated at this single temperature were used. Since temperature effects were small over the range considered negligible error could have resulted from this procedure.

Operating Procedure. The usual procedure in making a run was first to set the flow rate of the continuous phase. Then the flow rate of the discontinuous phase was increased gradually until a point was found where the column was barely flooding. When the column flooded after a change in the discontinuous flow rate, all flows were shut down and the column allowed to clear before starting again with a lower setting. Early experimentation with the procedure reversed and the discontinuous phase flow rate set first and held constant as the independent variable showed no significant difference in the flow rates at the flooding points. For the water-gasoline series in one-inch packing this is shown graphically by Figure 4, in which the discontinuous phase flow rate was made the independent variable for three of the ten runs. The continuous phase was used thereafter as the independent variable in all cases.

Flooding was first indicated by the appearance of fine bubbles of the light phase which bounced down below the packing support an inch or two and then slowly floated back up and disappeared into the packing again. As flooding continued, the size of the bubbles forced out the bottom of the packing increased and gradually an undulating layer of the light phase was built up immediately below the packing. Finally as the layer became thicker, the light phase flowed outward past the edge of the packing support and a string of drops could be seen rising outside of the expanding section to the top of the bottom section of the tower. The same pattern always occurred so that with the appearance of considerable bubbling below the packing support, flooding was positively noted; and the flows were shut down before much of the light liquid was driven over into the top of the bottom section.

Considerable time was required for a change in one of the flow rates to make itself felt throughout the column—largely in terms of changed holdup—and the manner of operation varied somewhat with the different liquid combinations used.

With the water-gasoline system it was possible to see through both phases at all times, resulting in the simplest operating procedure. The column was filled with liquids such that with no flow the bottom section was completely filled with heavy liquid, and the interface was statically at a height of about one inch over the top of the weir in the top section. When the flow of the discontinuous phase was started, the interface gradually rose in the top section as the holdup of light phase was built up in the tower. After some 15 to 30 min. at given flow settings the holdup became stabilized and the position of the interface as seen through the top windows became fixed. Water over carbon tetrachloride differential manometers, connected as shown in Figure 3, were used to indicate that the column had come to complete equilibrium before changing the flow rates. Changing holdup in the expanding section as well as the center section was reflected as a drift in the manometers. When the level of the interface in the top window and the deflection on the manometers became constant, the column was known to be at equilibrium; and the flow rate of discontinuous phase was increased by a small amount and the procedure repeated.

TABLE 2. PROPERTIES OF THE SYSTEMS [1,2]

Series	Continuous Phase	Discontinuous Phase	Packing	μ_c lb./ft.-hr.	μ_d lb./ft.-hr.	ρ_c lb./cu.ft.	ρ_d lb./cu.ft.	$\Delta\rho$ lb./cu.ft.	σ dynes/cm.
A	Water	Gasoline	1/2" Rings	2.13	1.86	62.3	49.0	13.3	42.7
B	Water	Gasoline	1-1/2" Rings	2.13	1.94	62.3	49.0	13.3	42.4
C	Water	Gasoline	1" Rings	2.13	1.94	62.3	49.0	13.3	42.1
D	57% Glycerol	Gasoline	1" Rings	18.8	1.94	71.7	49.0	22.7	34.1
E	Carbon Tet.	Water	1" Rings	2.27	2.15	98.7	62.3	36.4	44.8
F	Carbon Tet.	55% Glycerol	1" Rings	2.20	16.9	98.8	71.3	27.5	28.4
1	Water	Gasoline	1/2" Rings	2.27	2.23	62.4	50.4	11.9	37.6
2	Water	Gasoline	1/2" Rings	2.35	2.23	62.4	49.8	12.6	30.6
3	Water	Gasoline	1/2" Rings	2.37	2.23	62.4	49.8	12.6	20.6
4	Water	Gasoline	1/2" Rings	2.37	2.23	62.4	49.8	12.6	8.9
5	Water	N. I. E.	1/2" Rings	2.25	1.40	62.4	50.0	12.4	11.4
6	35% Glycerol	Toluene	1/2" Rings	6.70	1.43	67.8	53.5	14.3	28.1
7	Carbon Tet.	Water	1/2" Rings	2.23	2.23	99.0	62.4	37.2	44.8
8	Water	Gasoline	1/2" Saddles	2.23	2.23	62.4	49.8	12.6	37.0
9	Water	N. I. E.	1/2" Saddles	2.37	1.40	62.4	49.5	12.9	11.4
10	Water	Naphtha	1/2" Saddles	2.37	1.50	62.4	53.0	9.4	36.0
11	N. I. E.	Water	1/2" Saddles	1.40	2.37	49.5	62.4	12.9	11.4
12	Naphtha	Water	1/2" Saddles	1.50	2.37	53.0	62.4	9.4	36.0
13	Water	Naphtha	1/2" Rings	2.37	1.50	62.4	53.0	9.4	36.0
14	Naphtha	Water	1/2" Rings	1.50	2.37	53.0	62.4	9.4	36.0
15	Water	N. I. E.	1/2" Spheres	2.37	1.40	62.4	49.5	12.9	11.4
16	Naphtha	Water	1/2" Spheres	1.50	2.37	53.0	62.4	9.4	36.0

(1) At 25 C. for Series A-F

(2) Flooding Data for Series 1-16 Are Summarized in Reference (3)

TABLE 3. EXPERIMENTAL DATA

Series A				Series B			
U_c ft./hr.	U_d ft./hr.	U_d/U_c	Temp. °C	U_c ft./hr.	U_d ft./hr.	U_d/U_c	Temp. °C
186.	3.8	48.9	24.7	255.	40.8	6.38	25.6
146.	4.5	32.4	26.0	195.	59.3	3.29	23.1
115.	15.4	7.47	22.8	146.	83.7	1.74	21.8
71.5	44.6	1.60	24.3	120.	114.	1.05	26.1
52.2	63.9	0.817	26.7	98.0	134.	0.731	24.8
30.1	104.	0.289	27.1	98.0	156.	0.628	24.8
19.3	128.	0.151	29.3	64.3	209.	0.308	25.4
10.7	137.	0.054	28.0	35.3	390.	0.091	26.5

Series C				Series D			
289.	15.6	18.5	26.6	342.	10.4	32.9	30.2
202.*	42.8	4.72	26.8	276.	27.7	9.96	29.0
197.	42.8	4.60	26.0	221.	59.3	3.73	29.0
146.	79.6	1.83	24.2	182.	98.0	1.84	30.3
118.*	104.	1.14	26.0	144.	144.	1.01	28.3
98.0	130.	0.754	21.2	64.3	299.	0.215	21.8
64.3	194.	0.331	23.1	42.9	364.	0.118	26.9
64.3*	194.	0.331	25.2				
46.4	261.	0.178	26.1				
32.7	286.	0.114	26.6				

*Discontinuous phase independent variable

Series E				Series F			
322.	57.8	5.56	29.9	322.	28.9	11.1	31.0
269.	76.6	3.51	32.0	269.	54.1	4.97	28.1
214.	99.0	2.16	30.8	214.	85.7	2.56	27.5
161.	149.	1.11	28.2	161.	129.	1.25	25.1
108.	202.	0.534	26.8	108.	172.	0.603	28.3
54.1	361.	0.186	29.9	54.1	247.	0.219	29.5

Series	Distributor
A	92 9/64" holes
B-F	92 1/4" holes

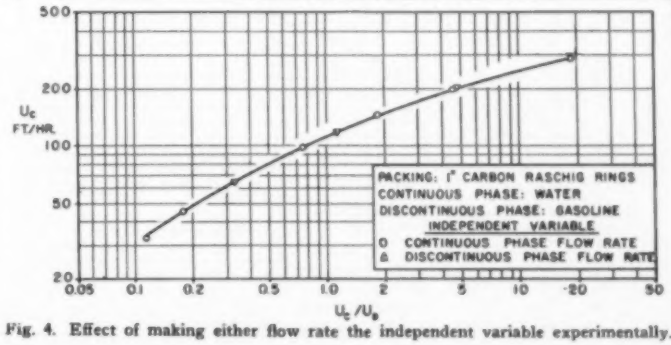

Fig. 4. Effect of making either flow rate the independent variable experimentally.

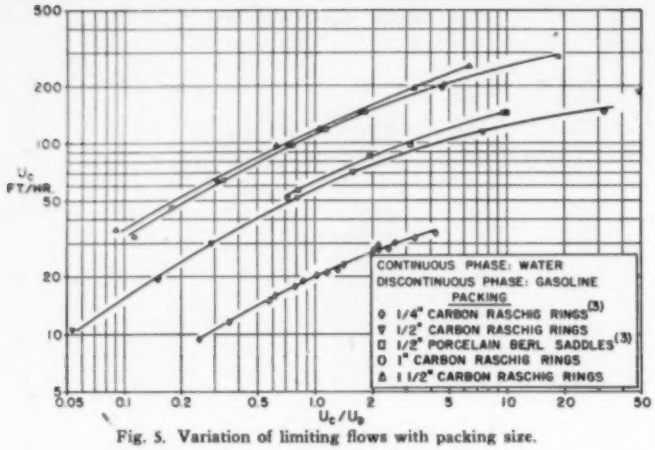

Fig. 5. Variation of limiting flows with packing size.

During the glycerol solution-gasoline and carbon tetrachloride-water runs, the continuous phase became murky so that it was impossible to see the bottom of the packing support to check flooding conditions. For these cases, the column was operated with an air head in the top of the bottom section in the space between the expanding section and the outside wall of the section. The pressure was controlled from an auxiliary air line such that the level of the liquid in the bottom section was forced down so that the air-liquid interface could be seen on the bottom windows. The level was still well above the packing support so that normal flows prevailed. One hour was allowed between small changes of the discontinuous phase flow rate to insure attainment of equilibrium, and flooding was detected by the buildup of a layer of light phase visible at the window.

Results

Experimental data are shown in Figures 5 and 6 and summarized in Table 3. Flooding points are reported as superficial velocities of each phase, feet per hour, based on the total column cross section. The continuous phase velocity in all cases is a smooth function of the velocity ratio, U_c/U_d, similar in shape to previous curves for smaller packings (*3*). As shown in Figure 5 column capacity decreases rapidly with decrease in packing size.

Interpretation of Results

Comparison with Previous Correlation. Figure 7 compares the present results with the correlation of Breckenfeld and Wilke represented by the solid curve on the figure. Reasonably good agreement is obtained with the water-gasoline system in one-half-inch and one-inch rings, but the data for glycerol-gasoline with high continuous phase viscosity, and for carbon tetrachloride-water and carbon tetrachloride-glycerol with high density difference fall seriously in error. The correlation appears to predict a falsely high dependence on continuous phase viscosity and density difference—effects which would be expected if the flow became significantly more turbulent in large packings where these variables exhibit less influence than in viscous or near-viscous flow. That high fluid turbulence prevailed in these runs was demonstrated by the fact that with the water-carbon tetrachloride system at large water flows some of the one-inch carbon rings were carried out of the top of the column, so that it became necessary to hold the packing down with a wire lacing.

Development of New Correlation. The mechanism of flooding in packed columns is not completely clear and experimental investigation has been hindered by inability to see what occurs within the interstices of the packing. Ballard and Piret (*1*) made detailed observation of liquid behavior in a 3.75-in. glass column packed with unglazed porcelain Raschig rings and described two types of column operation depending on whether the phase which preferentially wets the packing is made the continuous or dispersed phase.

In the present study, due to the opaque steel walls of the tower and cloudy appearance of the fluids, visibility was inadequate to detect variations in flow mechanism, and the flooding point was the only operating condition noted. However, nonpolar liquids which would be expected to preferentially wet carbon packing were made both continuous and discontinuous phases during the runs, and both types of flow noted by Ballard and Piret may have occurred.

In the runs of Breckenfeld and Wilke and in those of the present study, insofar as visibility permitted, the phase originally made discontinuous emerged from the packing in the form of droplets. This leads to the possible hypothesis that flooding occurs as a result of droplets of some certain size, characteristic of the particular packing and properties of the system, being unable to rise against the velocity of the continuous phase. Such a concept, although hypothetical, offers a model which can be utilized to make some physical interpretation of the effects of packing size and liquid properties on flooding velocities.

The void space open to the continuous phase in flow is less than the free void space of the packing due to holdup of discontinuous phase in the voids, and this available void fraction appears to decrease with increase in discontinuous phase flow. If the size of drop which is rejected at flooding is assumed constant for all flow rates the view may be taken that holdup of discontinuous phase develops with increase in flow rate of discontinuous phase so that the actual continuous phase velocity becomes equal to the rate of rise of the limiting sized drop. It may be further assumed that some limiting continuous phase velocity, $(U_c)_*$, could be estab-

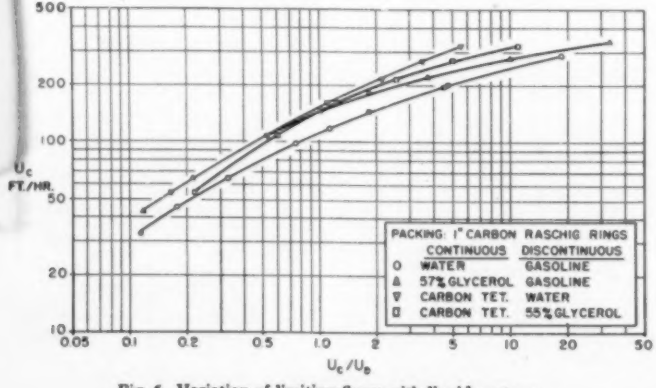

Fig. 6. Variation of limiting flows with liquid systems.

lished above which none of the discontinuous phase could enter the packing and all the voids in the packing would be open then to continuous phase flow. This assumption permits an estimate of limiting drop size to be made assuming the drops to be spherical and to obey the laws of frictional drag on settling spheres. It cannot be expected that these conditions will be fully met in practice, but the results may be of qualitative value and offer a theoretical framework for empirical correlation of experimental results.

To obtain the limiting continuous phase velocity it is necessary to extrapolate to zero velocity of discontinuous phase. It has been observed (*2, 3*) that the sum of the square roots of the continuous and discontinuous phase velocities is essentially constant for a given packing and liquid system, and the same relation obtained in this study. Figure 8 shows the fit of data for several packings to a line of unit negative slope as required for constancy of the sum of the square roots. Accordingly, the limiting continuous phase velocity for each system was taken as the square of the average of the sum of the square roots divided by the void fraction for the packing. Thus:

$$(U_c)_o = \frac{[(U_o^{1/2} + U_d^{1/2})_{av.}]^2}{F} \qquad (1)$$

where:

$(U_c)_o$ = limiting continuous phase velocity, ft./hr., based on actual cross section open to flow

U_c = continuous phase velocity based on free column cross section, ft./hr.

U_d = discontinuous phase velocity based on free column cross section, ft./hr.

F = dry void fraction of packing

Settling velocity of a sphere is related to diameter and fluid properties by the relation (*8*)

$$(U_o)_o = \sqrt{\frac{4gD(\rho_c - \rho_d)}{3\rho_c f}} \qquad (2)$$

where, in the present notation for rising fluid drops

D = drop diameter
ρ_c = continuous phase density
ρ_d = discontinuous phase density
g = acceleration of gravity
f = drag coefficient

In a preliminary effort to obtain a correlation, drop diameters were calculated for the data of this study and those of Blanding and Elgin (*2*) and Breckenfeld and Wilke as given in Tables 3 and 4 of their paper (*3*), using Equation (2) in conjunction with drag coefficients given by Perry (*7*). These calculated drop diameters ranged from approximately 0.02 in. to 0.09 in. over the range of packing sizes from ¼ in. to 1½ in. Reynolds numbers based on drop diameter ranged from approximately 3 to 200 suggesting the flow around the particles to be in transition from fully viscous to turbulent. Numerous attempts were made to relate these hypothetical drop diameters to physical properties of the fluids and packing. The most successful of these showed the drop diameter to be expressed approximately by the relation:

$$D = C\left(\frac{F}{a}\right)\left(\frac{\sigma\rho_c F}{\mu_c^2 a}\right)^{-0.25} = C\frac{F}{a}\phi^{-0.25} \qquad (3)$$

where:

$$\phi = \left(\frac{\sigma\rho_c F}{\mu_c^2 a}\right)$$

C = dimensionless proportionality constant

a = surface area of packing/unit volume

ρ_c = continuous phase density

μ_c = continuous phase viscosity

σ = interfacial tension

Hayworth and Treybal (*5*) have pointed out that the dimensionless group, ϕ, in slightly different form, arises in the application of dimensional analysis to the problem of drop formation in flow of liquids from nozzles.

Equation (2) may be divided by the Reynolds number, $D(U_c)_o\rho_c/\mu_c$, and rearranged to give:

$$\sqrt{\frac{4\mu_c^2}{3g\rho_c\Delta\rho D^3}} = \frac{\sqrt{f}}{\frac{(U_o)_o\rho_c D}{\mu_c}} \qquad (4)$$

Substituting D from (3) in (4) and combining numerical constants, noting that the drag coefficient f is a function of Reynolds number, gives:

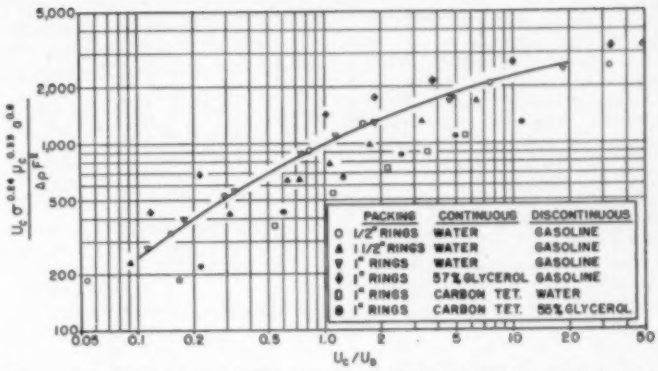

Fig. 7. Comparison of experimental data with Breckenfeld-Wilke correlation (*3*).

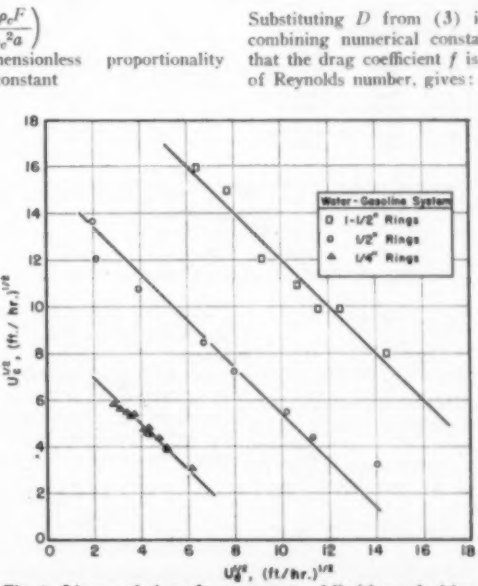

Fig. 8. Linear relation of square roots of limiting velocities.

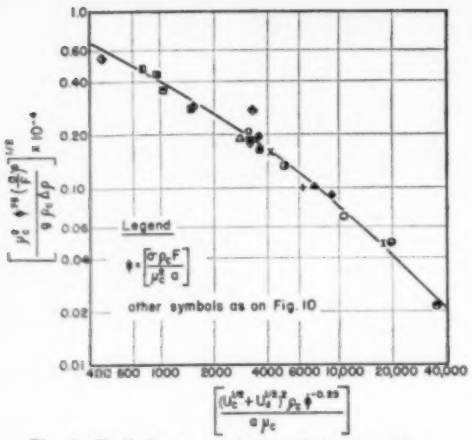

Fig. 9. Preliminary correlation of limiting flows.

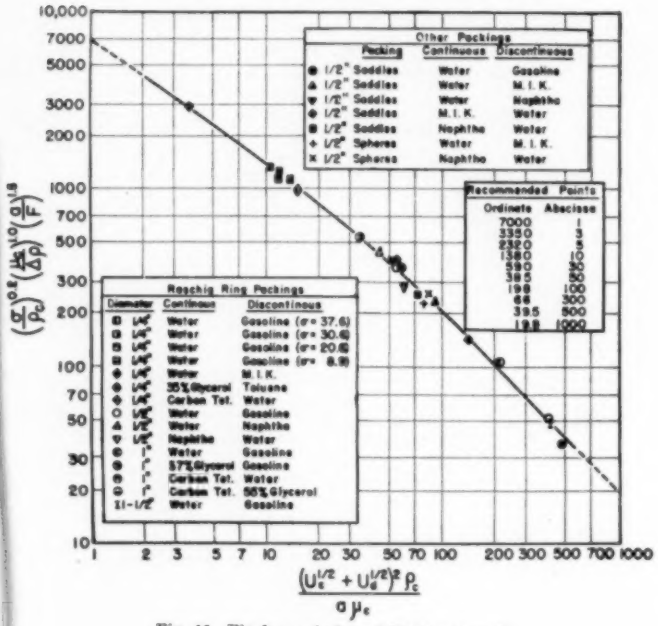
Other Packings
Packing | Continuous | Discontinuous
1/2" Saddles | Water | Gasoline
1/2" Saddles | Water | M. I. K.
1/2" Saddles | Water | Naphtha
1/2" Saddles | M. I. K. | Water
1/2" Saddles | Naphtha | Water
1/2" Spheres | Water | M. I. K.
1/2" Spheres | Naphtha | Water
Recommended Points
Ordinate | Abscissa
7000 | 1
3350 | 2
2320 | 5
1380 | 10
580 | 30
385 | 50
198 | 100
66 | 300
39.5 | 500
19.2 | 1000
Raschig Ring Packings
Diameter | Continuous | Discontinuous
Water | Gasoline (σ = 37.6)
Water | Gasoline (σ = 30.6)
Water | Gasoline (σ = 20.6)
Water | Gasoline (σ = 8.9)
Water | M. I. K.
35% Glycerol | Toluene
Carbon Tet. | Water
Water | Gasoline
Water | Naphtha
Naphtha | Water
Water | Gasoline
57% Glycerol | Gasoline
Carbon Tet. | Water
Carbon Tet. | 56% Glycerol
Water | Gasoline

Fig. 10. Final correlation of limiting flows.

$$\sqrt{\frac{\mu_c^2(a/F)^3\psi^{0.75}}{g\rho_c\Delta\rho}} = \psi(\text{Reynolds number}) \qquad (5)$$

where ψ is a function of Reynolds number to be determined. The Reynolds number is defined with the drop diameter D replaced by Equation (3), $(U_c)_s$ by Equation (1), and numerical constants omitted. Thus:

$$\text{Reynolds number} = \frac{(U_c^{1/3} + U_d^{1/3})^2\rho_c\psi^{-0.25}}{a\mu_c} \qquad (6)$$

Figure (9) indicates a fairly definite functional relationship between the left member of Equation (5) and the Reynolds number as defined above. However, the ability of the correlation to reproduce the experimental results is not as good as would be desired. It was therefore decided to proceed empirically to develop a more precise correlation within the same general framework of variables.

More generally, in view of the above preliminary correlation, it might be expected that:

$$\frac{(U_c^{1/3} + U_d^{1/3})^2\rho_c}{a\mu_c} = \text{function of } \rho_c, \Delta\rho, \mu_c, \sigma, g, a/F \qquad (7)$$

The left member of (7) is a Reynolds number similar in definition to that which has been used in the correlation of pressure drop in flow of gases through granular solids (6). The best empirical function of the variables of Equation (7), with the same scale as Figure (9), indicated the Reynolds number to be a function of the groups $(\sigma/\rho_c)^{0.1}(\mu_c/\Delta\rho)^{0.5}(a/F)^{0.75}$. To expand the graph the square of the groups was plotted against the Reynolds number as shown in Figure 10. The correlation is not dimensionless and has the units stated below:

$$\left(\frac{\sigma}{\rho_c}\right)^{0.2}\left(\frac{\mu_c}{\Delta\rho}\right)^{1.0}\left(\frac{a}{F}\right)^{1.5} = \psi(\text{Reynolds number}) \qquad (8)$$

where:

σ = interfacial tension, dynes/cm.
ρ_c = continuous phase density, lb./cu.ft.
μ_c = continuous phase viscosity, lb./(hr.)(ft.)
$\Delta\rho$ = density difference, lb./cu.ft.
a = surface area/unit volume, sq. ft./cu.ft.
F = dry void fraction, dimensionless
U_c, U_d = superficial velocities of continuous and discontinuous phases, ft./hr. (based on total column cross section)
ψ = function of Reynolds number denoted by curve of Figure 10

Figure 10, in the units stated above, constitutes the final correlation. As indicated in the legend of the figure the data of this and previous studies, Tables 1-3, are drawn into a single function. In view of the wide variety of packings and liquid properties included, the correlation is considered satisfactory.

Alternate Dimensionless Correlation. Applying dimensional analysis to Equation (7) gave as a possible functional relation the dimensionless groups of Equation (9):

$$\frac{(U_c^{1/3} + U_d^{1/3})^2\rho_c}{a\mu_c} = \text{function of}\left(\frac{\rho}{\Delta\rho}\right)\left[\frac{\sigma}{\rho_c g(F/a)^2}\right]\left[\frac{\mu_c^2 g(F/a)}{\sigma^2}\right] \qquad (9)$$

If it is further assumed that these groups enter as simple exponential terms, and the exponents on $\Delta\rho$, μ_c, a/F

are fixed at −1.0, 1.0 and 1.5 respectively on the basis of Figure 10, the following result is obtained:

$$\frac{(U_c^{1/2}+U_d^{1/2})^2\rho_c}{a\mu_c} = \text{function of}\left(\frac{\rho}{\Delta\rho}\right)^{1.0}\left[\frac{\sigma}{\rho_c g(F/a)^2}\right]^{1.0}\left[\frac{\mu_c^2 g(F/a)}{\sigma^2}\right]^{0.5}$$

$$= \text{function of}\left[\frac{\mu_c^2(a/F)^3}{(\Delta\rho)^2 g}\right]^{0.5} \qquad (10)$$

The variables of Equation (10) are plotted in Figure 11 giving an alternate correlation which is dimensionless. It should be noted that setting the exponents as just described results in elimination of interfacial tension as a variable. This is not in accord with experimental observation, but the error is not very serious for the range of interfacial tensions covered in these data.

By altering the settings of exponents slightly, other dimensionless plots may be obtained which retain all the variables of Equation (9) and also give reasonably good correlation. However, in absence of a more certain theory for the mechanism of flooding, and without sure knowledge that all variables which should be put into a dimensional analysis have been considered, use of cumbersome dimensionless groups does not seem justified. Until criteria for similarity among these systems have been more definitely established no greater theoretical significance can be ascribed to such dimensionless correlations than to a simple dimensional correlation based upon experimental observation.

Comment

Accuracy of Correlation. The present correlation inherently assumes constancy of the group $U_c^{1/2}+U_d^{1/2}$. Although this is not completely true, and has no obvious theoretical basis, the summation of the square roots seems to be a reasonable index of column capacity in the range of flow ratios usually encountered. Average deviation of $U_c^{1/2}+U_d^{1/2}$ for each flooding point in the data (a total of 160 points) from an average value for each series was 1.8%.

Accuracy of the correlation in prediction of column capacity is indicated by horizontal separation of the points from the curve of Figure 10. For the 22 systems reported this average deviation was 6.3%, and the maximum deviation (series C) was 15%. This average deviation coupled with 1.8% average deviation of $U_c^{1/2}+U_d^{1/2}$ from constancy would give a total average deviation for the entire correlation of about 10%.

Approximate Equations for Correlation. The curve of Figure 10 may be approximated by two intersecting straight lines, one with a slope of −0.75 in the range of modified Reynolds numbers less than 50, and the other with a slope of −1.0 for Reynolds numbers greater than 50. Equations for these lines may be simplified to give the following relations:

For Reynolds numbers less than 50:

$$(U_c^{1/2}+U_d^{1/2})^2 = 147{,}000\,\frac{\Delta\rho^{1.33}F^2}{\rho_c^{0.73}a^{1.0}\mu_c^{0.33}\sigma^{0.27}} \qquad (11)$$

For Reynolds numbers greater than 50:

$$(U_c^{1/2}+U_d^{1/2})^2 = 19{,}800\,\frac{\Delta\rho F^{1.5}}{\rho_c^{0.8}a^{0.5}\sigma^{0.2}} \qquad (12)$$

These equations fit the experimental points nearly as closely as the single smooth curve.

Comparison with Breckenfeld-Wilke Correlation. Equation (1) in the previous paper (*3*) may be expressed in the following form:

$$(U_c^{1/2}+U_d^{1/2})^2 = 6370\,\frac{\Delta\rho^{0.98}F^{1.98}}{a^{0.82}\mu_c^{0.32}\sigma^{0.26}} \qquad (13)$$

As it was developed on the basis of data for small packings, Equation (13) should be comparable to Equation (11). It will be noted that the effects of void fraction, surface area, viscosity and interfacial tension are quite similar in these equations, and that the principal difference lies in the use of $\Delta\rho^{1.33}/\rho_c^{0.73}$ in Equation (11) and $\Delta\rho^{0.98}$ in Equation (13). Comparison of the maximum relative changes in $\Delta\rho^{0.98}$ and $\Delta\rho^{1.33}/\rho_c^{0.73}$ over the liquid systems studied indicates that either could be used as the correlating variable with essentially the same result. For example, in comparing systems *A* and *E* the ratio of $\Delta\rho^{0.98}$ for systems *E* to $\Delta\rho^{0.98}$ for system *A* is 2.69. Similarly, the ratio of $\Delta\rho^{1.33}/\rho_c^{0.73}$ for the two systems is 2.72. Thus it may be concluded that within limitations of the present data Equations (11) and (13) are essentially equivalent, and that additional data or improved theory will be required to indicate conclusively which formulation of the variables is preferable. However, in view of the general application of Figure 10 to the entire range of Reynolds numbers, Equation (11), is recommended for Reynolds numbers less than 50, and Equation (12) for larger Reynolds numbers.

Limitations of Correlation. Range of packing properties considered has been fairly wide with exception of void fraction which varied from 0.50 to 0.74. It is probably too much to expect that a packing can be completely characterized by surface area per unit volume and void fraction, and the correlation may not be applicable to packings having

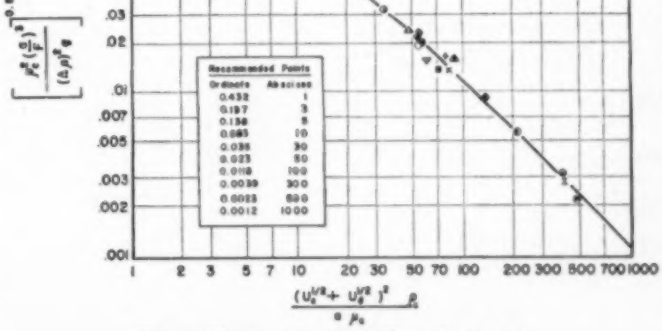

Fig. 11. Alternate correlation (Legend—Fig 10).

widely different characteristics, such as wire helices.

Liquid viscosity varied from approximately 1.4 to 19 lb./(hr.)(ft.) for both continuous and discontinuous phases among the systems considered. Liquid density varied from 99.0 to 49.5 lb./cu. ft., and density difference from 9.4 to 37.2 lb./cu.ft. A range of interfacial tensions from 44.8 to 8.9 dynes/cm. was covered. Extension of the correlation to liquid systems having properties beyond the limits considered above should be made with reservation.

Distributor hole diameter ranged from 0.10 in. to 0.14 in. for the studies in ¼-in. and ½-in. packings, and 0.25-in. holes were used with the 1-in. and 1½-in. packings. Although there is no indication that distributor hole size is an important variable, it is recommended that the correlation be used cautiously with distributors of greatly different design from those employed for the systems reported here.

The correlation embraces column diameters from 2.6 to 12 in. There is no evidence of significant wall effect over the range of ratios of packing diameter to tower diameter covered here. However, the problem of maintenance of uniform flow distribution in columns of large diameter has not been investigated, and accordingly the correlation should be extended to such columns with due caution.

Sample Design Calculation

Problem. It is desired to contact 4200 gal./hr. of heavy gasoline (discontinuous phase) with an aqueous solution in an extraction column packed with one-inch carbon Raschig rings. The liquids and packing may be assumed to have the properties of Series *C*, Tables 1 and 2. Mass-transfer considerations indicate that a volumetric flow ratio of gasoline to water of 0.64 should be used. Estimate the minimum allowable column diameter, i.e., for operation at the flooding point.

Solution. From data of Tables 1 and 2 calculate:

$$\left(\frac{\sigma}{\rho_c}\right)^{0.5}\left(\frac{\mu_c}{\Delta\rho}\right)\left(\frac{a}{F}\right)^{1.5} = 106$$

At the above value on Figure 10 read:

$$\frac{(U_c^{1/3} + U_d^{1/3})^2 \rho_c}{\mu_c a} = 187$$

Calculate

$$(U_c^{1/3} + U_d^{1/3})^2 = 378 \text{ ft./hr.}$$

Rearrangement of the quantity

$$(U_c^{1/3} + U_d^{1/3})^2$$

gives:

$$U_c = \frac{(U_c^{1/3} + U_d^{1/3})^2}{\left[1 + \left(\frac{U_d}{U_c}\right)^{1/3}\right]^2} = \frac{378}{(1+0.8)^2}$$

$$= 117 \text{ ft./hr.}$$

On the basis of experiment (Curve for Series *C*, Fig. 4), U_c at this flow ratio would be 136 ft./hr.

Minimum column cross section =

$$\frac{\text{Volumetric flow rate (cu.ft./hr.)}}{\text{Superficial velocity (ft./hr.)}}$$

$$= \frac{(4200)(0.1334)}{(0.64)(117)} = 7.49 \text{ sq.ft.}$$

Minimum diameter = 3.09 ft.

For conservative design a safety factor of 50% or more on column cross section is recommended.

Acknowledgment

Financial support of the Harry H. Hilp foundation in providing a fellowship for J. W. Crawford is gratefully acknowledged. Appreciation is extended to M. Amin Mandil and Robert De La Rue for valuable assistance, and to the Union Oil Company of California for providing the heavy gasoline.

Notation

a = sq.ft. packing surface/cu.ft. packed volume
F = cu.ft. void space/cu.ft. packed volume—dimensionless
Re = Reynolds number
U = superficial velocity at flooding point, (cu.ft.)/(sq.ft.)(hr.) or ft./hr.
μ = viscosity, lb./(ft.)(hr.)
ρ = density, lb./cu.ft.
$\Delta\rho$ = density difference between phases, lb./cu.ft.
σ = interfacial tension, dynes/cm.
σ_{wa} = surface tension of continuous phase against air, dynes/cm.
σ_{oa} = surface tension of discontinuous phase against air, dynes/cm.
ψ = function of Reynolds number

$_c$ means continuous phase
$_d$ means discontinuous phase
$_o$ denotes limiting continuous phase velocity

Literature Cited

1. Ballard, J. H., and Piret, E. L., *Ind. Eng. Chem.*, **42**, 1088 (1950).
2. Blanding, F. H., and Elgin, J. C., *Trans. Am. Inst. Chem. Engrs.*, **38**, 305 (1942).
3. Breckenfeld, R. R., and Wilke, C. R., *Chem. Eng. Progress*, **46**, 187 (1950).
4. Elgin, J. C., and Foust, H. C., *Ind. Eng. Chem.*, **42**, 1127 (1950).
5. Hayworth, C. B., and Treybal, R. E., *Ind. Eng. Chem.*, **42**, 1174 (1950).
6. Oman, A. O., and Watson, K. M., *Nat. Petroleum News*, Technical Section (Nov. 1, 1944).
7. Perry, J. H., *"Chemical Engineers Handbook,"* 3rd ed., McGraw-Hill Book Co., Inc., New York (1950).
8. Walker, W. H., Lewis, W. K., McAdams, W. H., and Gilliland, E. R., "Principles of Chemical Engineering," McGraw-Hill Book Co., Inc., New York (1937).
9. Weissberger, A. (Editor), "Physical Methods of Organic Chemistry," Vol. I. Part I, 2nd ed., pp. 253-96, 327-54, 355-412, Interscience Publishers, Inc., New York (1949).

Discussion

B. J. Lerner (University of Texas, Austin, Tex.): Did you determine the flooding characteristics of the packing support alone?

C. R. Wilke: No, we did not, although this is something that should be done. By placing the distributor above it, any interference of the packing support with the flow was eliminated. Blanding and Elgin, and also Breckenfeld, observed that location of the distributor below the packing support resulted in reduced column capacity.

B. J. Lerner: There is one other question which I have. What is done in cases where values of a and F are not obtainable? By that I mean packings like Fiberglas and Stedman mesh?

C. R. Wilke: In some data presented here we used the void fractions and surface areas per unit volume listed by the packing manufacturers with satisfactory results. In our own work we measured these properties. These properties must be obtained or estimated in some way in order to use the correlation.

Walter E. Lobo (M. W. Kellogg Co., New York, N. Y.): In Figure 10, where you have interfacial tension, I don't quite understand the effect—if the interfacial tension approached zero wouldn't the tower show an infinite capacity?

C. R. Wilke: That is true, and therefore the correlation should be extended cautiously to very much lower interfacial tensions than those we have studied here. We have assumed an exponential function for something that must be more complicated. If the interfacial tension is progressively reduced the correlations may eventually break down.

Walter E. Lobo: How do you explain the effect of interfacial tension even over the range which you have?

C. R. Wilke: We have speculated on this to some extent. It's not an apparent thing and we're not sure about it. A possible explanation is that lower interfacial tension enables the droplets to adapt themselves more easily to the interstices of the packing, and therefore they pass through with less resistance than when the interfacial tension is high.

T. K. Sherwood (Massachusetts Institute of Technology, Cambridge, Mass.): The final correlations which you presented and which show such excellent results, did have, in both ordinate and abscissa, a sufficient grouping of variables so that it isn't easy to understand what the real meaning of

the appearance of each variable may be. Since there are two or three of them appearing both in ordinates and abscissae one may wonder just what is going on. It sometimes happens that in such a graph the effect of a variable cancels out, or that the correlation looks better than when in a simpler form. I wonder if you happen to have any of what some people call "dead soldier plots," of the original data, compared with predicted values based on one or the other of these two correlations presented.

C. R. Wilke: I do not have any dead soldier plots of the data. The average deviation in prediction of $(U_c^{1/3} + U_d^{1/3})^2$, which is a direct measure of column capacity, was about 10%. The maximum error in prediction of this quantity for any single flooding point was possibly 35%. As you say, it is difficult to sort out any one variable by inspection of the correlation. (We have subsequently prepared Equations (11) and (12) which do this.) I might say qualitatively, that the effect of continuous phase viscosity seems to be largest with small diameter packings, i.e., small Reynolds numbers, then tapers off to lesser dependence at higher Reynolds numbers. Density difference, interfacial tension, void-fraction and surface area follow a similar trend according to Figure 10. Discontinuous phase viscosity seems to have little effect. It is difficult to study each variable independently, so that we cannot be sure at this point that our arrangement of the variables in the correlation is absolutely the best. Certainly further study will be desirable. We can say only that we have a method of presenting the variables which gives fairly good prediction of the data which are presently available.

The correlation may appear to be somewhat better than it is since some of the same variables are plotted in both ordinate and abscissa. Use of a modified Reynolds number, which is believed justified from a hydrodynamic viewpoint, leads to this method of plotting. The usual correlations of drag coefficients for settling velocities of solids in fluids are similar in character.

R. L. Savage (Case Institute of Technology, Cleveland, Ohio): I note in the drawing of the equipment that you were not using the usual overflow type of takeoff. Would you care to comment on that?

C. R. Wilke: The column was operated as a closed system. Previous studies have used a vented swing arm which held the liquid-liquid interface at a constant level at the top of the column. In the present case we found that the interface at the top would rise to accommodate the flow and would remain in a constant position for any given flow setting. Either procedure seems to be satisfactory.

Written Discussion

Howard K. Rae (National Research Council, Chalk River (Ont.), Canada: The data and correlations presented in this paper are a most welcome contribution and will prove useful in the design of extraction columns, as well as providing further insight into the theoretical aspects of packed column operation. There has long been a need for experimental data on the flooding of extraction columns of large diameter such as that used by these authors. It is to be hoped that future investigators will follow their lead in this respect.

On the basis of a general theoretical treatment the authors presented their data in the form of an empirical correlation. They also obtained a preliminary dimensionless correlation shown in Figure 9. From a study at Princeton University of the previously available data I had obtained a correlation by means of dimensional analysis which is worth while comparing with that presented by the authors.

It is known empirically that $U_c^{1/3} + U_d^{1/3}$ is a constant at the flooding point. The square of this constant can therefore be used as a characteristic velocity, U_o having a single value for any given choice of continuous and discontinuous phase in a particular column. The other variables which can be shown experimentally to have an effect on flooding are ρ_c, $\Delta\rho$, σ, μ_c, a, and F. Since it is the difference in weights of the two phases which is important, rather than the difference in masses, the value of $\Delta\rho$ is multiplied by g. Application of the methods of dimensional analysis yields four dimensionless groups to be used in correlating flooding data. These are $(U_o\rho_c/\mu_c a)$, a modified Reynolds number; $(\Delta\rho g\rho_c/\mu_c^2 a^3)$, similar to the $K_{\Delta\rho}$ term used by Elgin and Foust (*3*) in correlating flooding data in solid-liquid systems; $(\sigma\rho_c/a\mu_c^2)$, a group which includes the effect of interfacial tension; and F, the fraction void. Using the data of Blanding and Elgin (*1*) and Breckenfeld and Wilke (*2*) a correlation for data on Raschig rings and Berl saddles was obtained by plotting

$$F\left(\frac{\Delta\rho g\rho_c}{\mu_c^2 a^3}\right)\left(\frac{\sigma\rho_c}{\mu_c^2 a}\right)^{-0.15}$$

against $U_o\rho_c/\mu_c a$. By including the data of Crawford and Wilke the correlation was extended as a smooth curve to higher Reynolds numbers. More recently, upon the suggestion of Doctor Wilke that the data of Blanding and Elgin for clay spheres did not fit this correlation, I modified the exponents on the groups to obtain the improved correlation shown in Figure A. All the data fit the curve with an average deviation of 10%.

The problem of correlating flooding velocities with the physical factors involved is a complex one. The data presently available are limited in the range of variables studied, and are not of high accuracy. A number of possible methods, either empirical in approach or dimensionless, will yield correlations which all fit the data equally well, and hence do not permit much discrimination amongst them. It would appear that a dimensionless type of correlation has a sounder basis than an empirical type. Certainly, in comparing flooding in packed extraction columns with related phenomena the former approach has much to recommend it.

Literature Cited

1. Blanding, F. H., and Elgin, J. C., *Trans. Am. Inst. Chem. Engrs.*, **38**, 305 (1942).
2. Breckenfeld, R. R., and Wilke, C. R., *Chem. Eng. Progress*, **46**, 187 (1950).
3. Elgin, J. C., and Foust, H. C., *Ind. Eng. Chem.*, **42**, 1174 (1950).

(*Presented at Forty-third Annual Meeting, Columbus, Ohio.*)

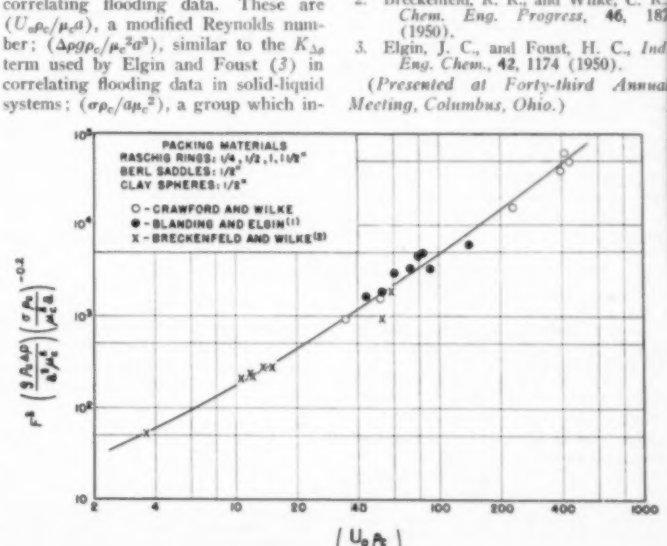

Fig. A. Correlation of flooding velocities.

PRESSURE DROP OF FLUID POLYSTYRENE IN CONDUITS

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PRESENT-day methods of calculating pressure drop of liquids flowing in conduits are sufficiently accurate for engineering purposes in most cases. However, when pressure drops for non-Newtonian liquids are calculated by such methods, which are based on Newton's relations, results may be badly misleading.

Many commercial fluids which flow through pipes and channels are not true fluids. With these materials apparent viscosity may change, even isothermally, as much as several thousand per cent from zero shear conditions (*6*). Obviously, then, Newtonian concepts cannot have much value here, and it is necessary to apply other principles.

For fluids which behave as true plastics Binder and Busher (*1*) have revised the evaluation of Reynolds' number and shown that agreement with experimental data is improved.

As far as can be determined no one has yet suggested a satisfactory method for handling engineering calculations for fluids which are pseudoplastic. It is the purpose of this paper to offer such a suggestion for the particular fluid polystyrene.

Derivation of Formulae. Spencer and Dillon (*8*) report that their experimental results on the flow of polystyrene through capillary tubes may be described by means of the following empirical formula:

$$\frac{1}{\eta_e} = \frac{1}{\eta_o}\left(1 + k\tau_w + \frac{(k\tau_w)^2}{2!} + \frac{(k\tau_w)^3}{3!} + \frac{(k\tau_w)^4}{4!}\right) \qquad (1)$$

η_e, the "apparent viscosity," is determined from the experimental conditions by Poiseuilles law:

$$\frac{1}{\eta_e} = \frac{8qL}{\pi r^4 \Delta p} \qquad (2)$$

and τ_w, the shear stress at the tube wall, is given by:

$$\tau_w = \frac{\Delta p r}{2L} \qquad (3)$$

Combining (*2*) and (*3*),

$$\frac{1}{\eta_e} = \frac{4q}{\pi r 3 \tau_w} \qquad (4)$$

Equation (1) may be written then in the dimensionless form:

$$\frac{4k\eta_o q}{\pi r^3} = k\tau_w + (k\tau_w)^2 + \frac{(k\tau_w)^3}{2!} + \frac{(k\tau_w)^4}{3!} + \frac{(k\tau_w)^5}{4!} \qquad (5)$$

This equation for flow through tubes is plotted graphically in Figure 1 to facilitate calculations. The functions plotted, X and $F_{(X)}$ are given by:

$$X = k\tau_w = \frac{k\Delta p r}{2L} \qquad (6)$$

or

$$\Delta p = \frac{2LX}{kr_w} \qquad (6a)$$

and

$$F_{(X)} = \frac{4k\eta_o q}{\pi r_w^3} \qquad (7)$$

Flow between stationary parallel plates may be determined from Equation (5) by the following procedure:

First, the relationship between shear stress and rate of shear is determined from Equation (5) by the method of Burgers (*3*).

It is assumed † that the rate of shear is a function of the shear stress alone, *i.e.*,

$$-\frac{dv}{dr} = \phi(\tau) \qquad (8)$$

† This assumption, as shown by Buchdahl (*2*) is incorrect under certain conditions for molten polystyrene; at temperatures below 200° C. the rate of shear is a function of time also.

Burgers shows that the function $\phi(\tau)$ may be obtained by means of the relationship:

$$\phi(\tau) = \frac{1}{\pi r^3}\left(\tau_w \frac{dq}{d\tau_w} + 3q\right) \qquad (9)$$

Substituting in Equation (9) the value of q and $dq/d\tau_w$ obtained from Equation (5) by solving for q and differentiating, one obtains:

$$\phi(\tau) = \frac{1}{k\eta_o}\left(k\tau + 5/4(k\tau)^2 + 6/4\,\frac{(k\tau)^3}{2!} + 7/4\,\frac{(k\tau)^4}{3!} + 8/4\,\frac{(k\tau)^5}{4!}\right) \qquad (10)$$

The subscript $(_w)$ is dropped in Equation (8) because the shear stress, in simple shear, is constant throughout the cross section.

The fluidity (reciprocal of apparent viscosity) is the ratio of rate of shear to shear stress, or

$$\frac{1}{\eta_e} = \frac{dv/dr}{\tau} = \frac{\phi(\tau)}{\tau} = \frac{1}{\eta_o}\left(1 + \frac{5k\tau}{4} + 6/4\,\frac{(k\tau)^2}{2!} + 7/4\,\frac{(k\tau)^3}{3!} + 8/4\,\frac{(k\tau)^4}{4!}\right) \qquad (11)$$

This equation, due to the presence of odd and even powers of the shear stress, will give incorrect results when negative values of the shear stress are used. Strictly speaking, only even powers should have been employed in the original empirical Equation (1). However, as long as the use of negative values of the shear stress is avoided, the numerical results will be correct (*9*).

For flow between broad, stationary parallel plates, of spacing $2r_w$ and width b, the velocity of flow at a distance (r) from the mid-plane (with respect to the mid-plane) will be:

$$V = r\phi(\tau) \qquad (12)$$

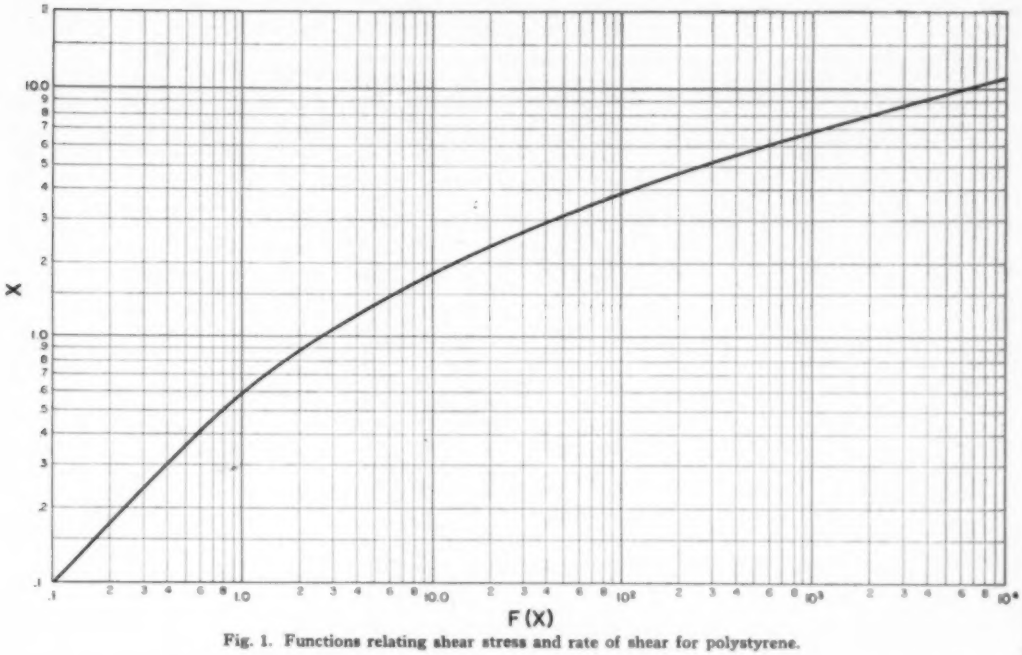

Fig. 1. Functions relating shear stress and rate of shear for polystyrene.

The volume rate of flow of an element of thickness dr, width b, and velocity V, will be:

$$dq = bV\,dr \qquad (13)$$

Since flow is symmetrical with respect to the mid-plane, the total flow will be

$$Q = 2b\int_{o}^{r_w} V\,dr = -2b\int_{o}^{r_w} r\phi(\tau)\,dr \qquad (14)$$

Substituting the value of $\phi(\tau)$ from Equation (8) and the value of

$$(\tau) = \frac{pr}{L}$$

the result is, upon integrating

$$3/2\,\frac{k\eta_o q}{b(r_w)^2} = k\tau_w + 15/16\,(k\tau_w)^2 + 9/20\,(k\tau_w)^3 + 7/40\,(k\tau_w)^4 + 1/28(k\tau_w)^5 \qquad (15)$$

where

$$\tau_w = \frac{\Delta p r_w}{L} \qquad (16)$$

The numerical solutions to this equation are (within experimental error) identical with those of Equation (5), so that Figure 1 may be employed also in calculations involving flow between parallel plates, by using the relationships:

$$X = k\tau_w = \frac{k\Delta p r_w}{L} \qquad (17)$$

or

$$\Delta p = \frac{XL}{kr_w} \qquad (17a)$$

and

$$F_X = 3/2\,\frac{k\eta_o q}{br_w^2} \qquad (18)$$

Use of these equations (and Fig. 1) in calculations requires knowledge of the two constants, K and η_o.

η_o, the viscosity at rest, or limiting viscosity at zero shear stress depends on several factors such as polymer molecular weight, solvent type and concentration, and temperature. Usually it can be determined with sufficient accuracy in a viscosimeter employing low shear stresses (below about 3×10^3 dynes/sq.cm.).

The constant k, however, can be determined only by measurements at high shear stresses. On the basis of available data (*10*), it appears that the constant k within the commercial molecular weight range depends chiefly on the concentration of solvent or other volatile material, as shown in Figure 2, where k is given in units of sq.ft./lb. force.

Calculation of pressure drop from flow data is performed by:

a. Calculating a numerical value of $F_{(X)}$ (for tubes) from Equation (7) or (for plates) from Equation (18).
b. Reading the corresponding value of X from Figure 1.
c. Inserting this value of X in Equation (6a) (or 17a) and solving for Δp.

Discussion of Data

Several opportunities have arisen for rough measurements of pressure drop of fluid polystyrene in actual plant operations. In every case, however, the plant was being operated for some other purpose so that it was not possible to vary operating conditions in order to obtain a wide range of values for the variables.

Four different apparatus setups were checked. The equipment description and polymer conditions are shown in Table 1.

By "solution viscosity" is meant the viscosity in centipoises of a solution of 10% by weight of polymer in toluene, measured at 25° C. Solution viscosity increases as polymer molecular weight increases.

Temperatures were measured by thermocouples encased in metallic wells. Checking and calibrating these thermocouples followed regular plant instrument department procedures, and temperatures are probably accurate to within ±2° C. Runs *B*, *C* and *D* were isothermal. In run *A* the temperature used is an arithmetic average of an inlet temperature of 213 and an outlet temperature of 203° C.

The per cent solvent should require no explanation except in the case of runs *A* and *B*. The volatiles are styrene, ethylbenzene, dimers, trimers, and such

other low boiling materials as remain when 99% styrene is incompletely polymerized.

Runs *A* and *D* involve pipe with bends as tabulated. In both cases the flow is far down in the streamline region. No reliable method for correcting for the effect of the bends was found in the literature. However, it is certain that the effect would be small, so it has been ignored.

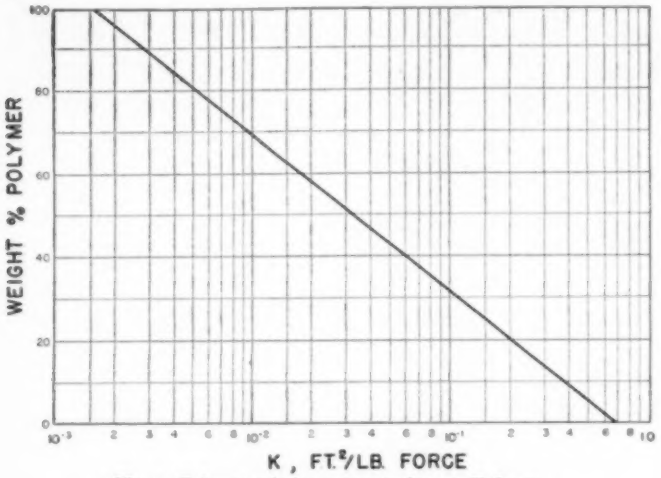

Fig. 2. Polymer solution concentration vs. K factor.

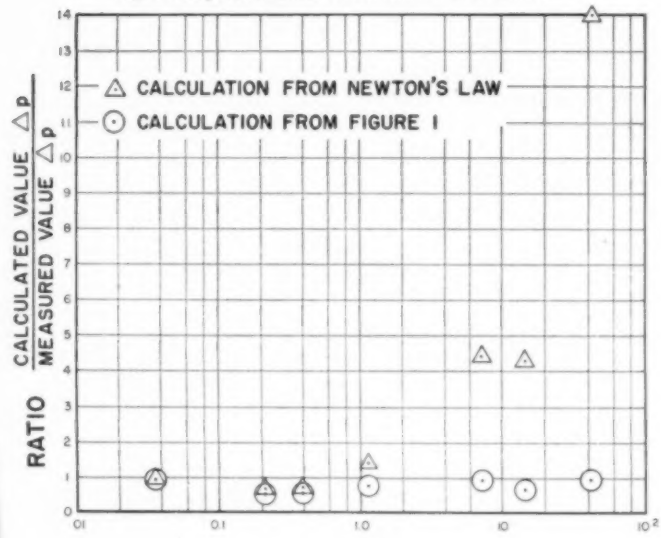

Fig. 3. Results—Ratio calculated to actual pressure drops vs. rate of shear function.

TABLE 1.

Run	Polymer Solution Viscosity Poises	T. °C.	Solvent	% Solvent by Weight	Apparatus
A	30	208	Volatiles	1.75	40 ft. of 3-in. sched. 40 pipe, two long radius 90° bends
B	30	193	Volatiles	1.75	6-in. O.D. annular, 1 in. long, .043-in. clearance
B_1	28	183	Volatiles	1.5	6-in. O.D. annular, 3 in. long, .100-in. clearance
C	45	100	Methyl chloride	9.7	4-in. O.D. annular, 24 in. long, .263-in. clearance
C_1	45	128	Methyl chloride	9.7	4-in. O.D. annular, 24 in. long, .263-in. clearance
D	35	47	Ortho di-chlor benzene	82.4	27.1 ft. of 3-in. sched. 80 pipe, four short radius return bends
D_1	35	48	Ortho di-chlor benzene	82.4	27.1 ft. of 3-in. sched. 80 pipe, four short radius return bends

Table 2 lists the values for each variable used in the calculations. From the polymer conditions listed in Table 1, η_0 was estimated by a correlation of data (*4*) on zero shear viscosity vs. temperature, solvent content, and solution viscosity of various polystyrenes. An extrusion viscosimeter of the type suggested by Nason (*7*) was used in collecting the data on which the correlation is based. The accuracy of the η_0 values used is believed to be within ±50%.

K was read from Figure 2.

Flow quantity was measured in all cases by weighing the material flowing in a measured time interval.

Pressure drops were taken as the difference between readings of two Bourdon tube gauges. The gauges were calibrated at installation but no record was kept of the time since installation, nor were the gauges removed for a calibration check following operation.

Flow of material, except in run *A*, was steady and nonpulsating. The source of pressure for run *A* caused fluctuations of ±20 lb./sq.in. about the median pressure on the inlet gauge. The cycle of pressure was approximately 10 sec. No pressure fluctuations were evident on the discharge gauge.

Discussion of Calculations. Considering the results, as tabulated in Table 2, F_X was calculated by substituting the tabulated values of the variables in Equation (*7*) for runs *A* and *D*, and in Equation (*18*) for runs *B* and *C*. *X* was then read from Figure 1 and the proper value of the variables substituted in Equations (*6a*) and (*17a*). Results are shown as "calculated Δp."

The parallel plate equations were used as the best available approximation for those runs where flow occurred in an annular space.

Equations (*6a*) and (*7*) reduce to Poiseuilles' equation if $X = F_X$. Accordingly, to calculate the Newtonian Δp, it was only necessary to multiply the results in col. II by F_X/X. The same reasoning applies for the case of parallel plates, where Equations (*17a*) and (*18*) can be reduced to the Newtonian relation.

Results

A graph of results (Fig. 3) wherein the ratio of the calculated pressure drop to the measured value is plotted against $F_{(X)}$ shows that the Newtonian method begins to lose accuracy in the $F_{(X)}$ range .1 to 1.0. Deviation becomes increasingly greater as $F_{(X)}$ increases. On the other hand the method described in this paper appears to hold approximately the

same accuracy throughout the range investigated.

Acknowledgment

The authors wish to acknowledge the assistance of several chemists and engineers of The Dow Chemical Co. in furnishing operating data. They are indebted also to The Dow Chemical Co. for permission to publish the data.

Notation

η_o = limiting viscosity, (lb. force)(sec.)/(sq.ft.)
η_e = apparent viscosity at stress τ_w, (lb. force)(sec.)/(sq.ft.)
τ = shear stress, lb. force/sq.ft.
τ_w = shear stress at wall, lb. force/sq.ft.
k = a constant, sq.ft./lb. force
r = distance from center of flow channel to any stratum, ft.
r_w = distance from center of flow channel to wall, ft.
b = width, ft.
L = length, ft.
V = velocity, ft./sec.
q = volumetric flow rate, cu.ft./sec.
Δp = pressure drop, lb./sq.ft.
X = $k\tau_w$, dimensionless
$F_{(X)}$ = function of X from Fig. 1, dimensionless
$\phi(\tau)$ = function of τ equal to the rate of shear, secs.$^{-1}$

Literature Cited

1. Binder, R. C., and Busher, J. E., *J. Applied Mechanics*, **68**, A101 (1946).
2. Buchdahl, R., *J. Colloid. Sci.*, **3**, 87 (1948).
3. Burgers, J. M., "First Report on Viscosity and Plasticity," Nordemann, New York (1939).
4. Dow Chemical Co., Private communication.
5. Ferry, J. D., *J. Am. Chem. Soc.*, **64**, 1323 (1942).
6. Greenblatt, J. H., and Fensom, D., *Ind. Eng. Chem.*, **39**, 1037 (1947).
7. Nason, H. K., *J. Applied Phys.*, **16**, 338 (1945).
8. Spencer, R. S., and Dillon, R. E., *J. Colloid. Sci.*, **4**, 241 (1949).
9. Spencer, R. S., Private communication.
10. Spencer, R. S., Based on data of Ferry (*5*) and Spencer and Dillon (*8*).

Discussion

Eli Perry (Monsanto Chemical Co., Springfield, Mass.): The correlation suggested has been shown to be useful over the range tested. The question arises as to the limit beyond which large errors will arise. For the 3-in. pipe, only flow in the Newtonian range was encountered and conventional as well as the suggested correlation agree with measured values of pressure drop. Where high shear stress and hence non-Newtonian flow was encountered, pressure-drop data are shown for narrow annuli only. The equation of Spencer and Dillon which is used in the derivation was developed using data from flow of styrene plastic through annuli whose dimensions were of the same order of magnitude. Are any data available for flow of the plastic through large diameter tubes at a shear stress in the range where non-Newtonian flow characteristics prevail, such that complicating effects of plug flow might interfere?

J. E. Pierce: Spencer and Dillon used capillary tubes, not annuli. However, the capillary diameters were of the same order of magnitude as the clearance of the annuli shown in these data, and your question is pertinent. We just don't have any data for non-Newtonian flow in large tubes. Since such data obviously would require a large flow of material and a high pressure drop it probably will require very special circumstances to make such tests economically feasible.

Wilmer I. Kranich (Worcester Polytechnic Inst., Worcester, Mass.): You say that at low rates of shear the fluid appears to obey the Newtonian relationship. Might it not be that the agreement between the calculated and the observed values happens because at low rates of shear you are using a viscosity under conditions approaching that at which the viscosity was obtained originally? If you have determined a viscosity at zero shear, and in the pipe at low rates of shear you are also approaching zero shear, my point is that probably the fluid is not obeying Newtonian flow but that it just appears to be doing so because the conditions are similar to those of the experimental determination of the viscosity?

J. E. Pierce: Actually, the experimental determination of viscosity is made in a capillary tube at several different rates of shear which may be quite high, and then extrapolated down to zero shear.

The polymer composition, the solvent concentration, and the temperature were the same in the laboratory determination as they were in the plant runs on which our data are based. Otherwise conditions are different. Tube size, length, pressure gradient, and quantity flowing all differed. The resultant rate of shear might or might not be the same as that used in the laboratory, depending on the shear rate points used in the laboratory determination.

Our conclusion, then, is that at low rates of shear we do get Newtonian-type flow, because we can use an independently determined constant viscosity throughout a range of pressure gradients and find the flow is proportional to the pressure gradient.

(Presented at Forty-third Annual Meeting, Columbus, Ohio.)

TABLE 2.

Run No.	Zero Shear Viscosity η_o (lb. force)(sec.)/(sq.ft.)	Material Constant k sq.ft./lb. force	Flow Rate q cu.ft./sec.	Annulus: Tube Radius r_w ft.	Annulus: Circumference b ft.	Annulus: Clearance $2r_w$ ft.	Length L ft.	Shear Functions: $F_{(X)}$	Shear Functions: X	Pressure Drop: Δp Measured lb./sq.ft.	Pressure Drop: Δp Newtonian lb./sq.ft.	Pressure Drop: Δp Calc'd lb./sq.ft.
A	84.0	1.65×10^{-3}	4.33×10^{-4}	.134	.....	.....	40.0	.0985	.0565	14.4×10^{5}	13.5×10^{5}	13.8×10^{5}
B	206	1.65×10^{-3}	4.30×10^{-4}	.....	1.57	.00358	.0814	43.6	3	87.7×10^{5}	1.230×10^{5}	84.7×10^{5}
B_1	368	1.65×10^{-3}	4.46×10^{-4}	.....	1.57	.00834	.250	14.8	2.1	125×10^{5}	537×10^{5}	76.3×10^{5}
C	2000	2.8×10^{-4}	1.10×10^{-4}	.....	1.06	.0219	2	7.24	1.6	102×10^{5}	449×10^{5}	98.5×10^{5}
C_1	279	2.8×10^{-4}	1.25×10^{-4}	.....	1.06	.0219	2	7.24	1.6	49×10^{5}	68.2×10^{5}	38.2×10^{5}
D	26×10^{-4}	2.3×10^{-1}	.501	.121	.....	.....	27.1	.215	.19	7.2×10^{5}	4.19×10^{5}	3.5×10^{5}
D_1	26×10^{-4}	2.3×10^{-1}	.910	.121	.....	.....	27.1	.39	.30	10.1×10^{5}	7.57×10^{5}	5.89×10^{5}

AIR POLLUTION AT LOW ALTITUDES
Techniques for Study

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CONTAMINANTS in the air have long been a subject of study and controversy. References frequently go back to early English history for the beginnings of these discussions. Today, most studies of air contaminants are concerned with large centers of industrial activity. This is natural, since moderate amounts of contaminants in the air create no human problem. Only when the air becomes overloaded with contaminants does the problem become serious. This overloading of the air may result from numerous small sources of contaminants over a large area, or a single concentrated source of contaminants, or any combination of these two conditions.

The seriousness of the problem depends not only on density of contamination but also on the surroundings. If no population center or valuable vegetation is near by, natural dispersion may so dilute the contaminants as to make them harmless. If air pollution and its economic control are to be understood the first step must be the development of a technique for measuring the amounts of contaminants in the air over and around industrial areas.

Nearly all studies of air contaminants have been based on sampling at ground level. However, it is also necessary to study the concentrations of contaminants at various altitudes over the area involved and their movement under various meteorological conditions. It is important, therefore, to consider the methods which are available for studying the concentrations of air contaminants and the meteorological elements which control their movement in the lower few hundred or few thousand feet of the atmosphere—the "earth-bound contaminant layer" of air.

A method, known as the Battelle Technique, has been developed for elevating various instruments to low altitudes for scientific observations. It consists of using one or more Kytoons (kite-balloons, which derive part of their lift from helium and part from air movement) as a skyhook, shown in Figure 1. In this way, measurements or samples may be secured continuously from the desired altitude and along any desired line.

Fig. 1. Kytoons used as skyhooks for taking air samples at different altitudes.

Early Work

A study of the air above ground level was made in 1940 by Hewson and Gill (*1*). Their studies of the concentration of sulfur dioxide in the atmosphere over Trail, B. C., and the Columbia River valley showed the importance of meterology in understanding the movement of this contaminant in the air. In addition to making meteor-

ological measurements and chemical determinations at ground level, they used a kite-balloon for determining the concentration of sulfur dioxide and the temperature at fixed positions up to 1500 ft. above the ground. Theories for the diffusion of gases have been advanced by Bosanquet and Pearson (*1*) and Sutton (*10*).

More recently, steel towers have been used for meteorological observations by Maynard Smith at the Brookhaven (L.I.) National Laboratory (*9*), by Huss and Portman (*5*) at the University of Akron, by Gerhardt (*3*) at the University of Texas, and many others. Practically all this work was based on measurements at fixed locations.

During World War II the armed forces developed a wiresonde supported by a Kytoon for determining the lapse rate (rate of temperature change with change in altitude) and relative humidity at altitudes up to 2000 ft. This technique has been used also for recording temperature measurements up to 3000 ft. at the Oak Ridge National Laboratory (*7*).

Sampling of Gases. The sampling and analysis of gases at ground level have been carried on by many investigators. Since the atmosphere is a three-dimensional medium, observations of contaminant concentrations at various altitudes above the ground should prove useful. To obtain these data, a new technique has been developed which samples the air at various altitudes and brings the sample down to the ground level for analysis. A polyethylene tubing is raised to the desired altitude by one or more Kytoons, as shown in Figure 2. This tubing may be maintained at the desired altitude for long periods of time, while the gas is being sampled continuously. This gas may then be analyzed by any of the conventional methods.

It has been found that rubber tubing is not satisfactory for conveying sulfur dioxide because of its permeability. An experiment showed that polyethylene is suitable for this purpose. A Thomas Autometer was used to record the sulfur dioxide content of a synthetic mixture. This mixture was then passed through 374 ft. of polyethylene tubing, and the analysis again made by the Autometer. It was found necessary to correct for the lower pressure when the gas was passed through the tubing. Results are shown in Table 1.

These results were obtained by alternately passing the gas mixture through the tubing, and then connecting the gas mixture directly to the Autometer. It will be seen that these results are within the experimental accuracy of the Autometer. When the polyethylene tubing is disconnected from the synthetic-gas source, the Autometer drops to less than 0.1 p.p.m. within five minutes. When it is reconnected to the synthetic-gas source, it rises to the normal value within five minutes. Since there is a lag both in the Autometer and in the time required for the gas to pass through the tubing, it is evident that equilibrium is rapidly established in this equipment.

Sampling of Aerosols. Aerosols have been sampled at ground level and from airplanes flying at altitudes of 1000 ft. and higher. A variation of the Kytoon technique may be used to secure samples at lower altitudes.

In order to secure these samples, it would be unsatisfactory to bring the air to ground level through a tube before collecting the sample. The particulate matter would probably become electrostatically charged and would adhere to the tubing. A more satisfactory method is to raise the sampling instrument to the required altitude and collect the sample. In this way, no particles are lost in bringing the air to ground level.

Early experiments were made using a midget impinger as the sampling device (Fig. 3). The vacuum for the operation of the impinger was furnished by the polyethylene tubing extending to the ground. This equipment operated satisfactorily within its recognized limitations (*2, 8*).

Since a more versatile aerosol collector was desired, the electrostatic precipitator has been adapted for this purpose. The power supplies for this equipment are maintained at ground level and are delivered to the precipitator and fan through a high-voltage and a low-voltage cable, respectively. The electrostatic precipitator and the cables are shown in Figure 4. In Figure 5, the precipitator is shown suspended from the Kytoons. Results from this method have proved satisfactory. The importance of this use of Kytoons lies in providing equipment which permits the sampling of aerosols by any one of a number of methods at various altitudes, limited only by the weight of the equipment required.

In highly industrialized centers, it has been difficult to determine the contribution which each plant makes to the total load of contaminants in the air. The Kytoon technique provides a means of solving this problem. The contaminant in question can be determined at several altitudes and at several points in two vertical planes above the ground, one to windward of the plant, and the other to leeward. The average of the contaminant load in the air may be determined for each plane, and the difference provides an index to the contribution of the plant to the total contaminant load in the air. It has not been possible to make this comparison before.

Fig. 2. Sampling tube raised to the desired altitude for sampling air.

Fig. 3. Sampling air at low altitude using a midget impinger.

TABLE 1.—ANALYSIS OF SYNTHETIC SULFUR DIOXIDE MIXTURES

SO_2 Connected Directly to Autometer, p.p.m.	SO_2 Passed Through 374 ft. of Polyethylene Tubing (corrected for pressure drop), p.p.m.
2.1	2.3
2.2	2.5
2.5	2.5
2.5	2.5

Fig. 4. Electrostatic precipitators with reels of wire and control equipment.

Meteorological Elements. It has been mentioned that the armed forces used a wiresonde for measuring lapse rate and relative humidity. The Kytoons raised the wiresonde to the desired altitude (See Fig. 6). In the past, the only widely used method for measuring wind velocity at various heights, which did not depend upon fixed structures, was the free-balloon technique. The first observation for these balloons is usually 600 to 1000 ft. above the ground and so does not give a reliable indication of the wind velocity at lower altitudes.

For an understanding of the movements of air contaminants, it is essential that the wind velocity and direction at chimney-top level and higher be known. To fill this need, a hot-wire anemometer has been adapted for use with Kytoons. The tiny thermopile is raised to the desired level, and the necessary power input and potential difference of the thermocouples are brought to ground level by a three-wire cable. By determining the wind velocity and direction at properly spaced levels, much information about the wind structure may be obtained. These data will be valuable in studying the movement of air contaminants in the low-altitude layers of the atmosphere.

A typical series of measurements is given in Table 2. These measurements were made on the leeward side of an industrial building 70 ft. high, with a stack reaching 100 ft. above ground level. The effect of the building and stack up to 100 ft. is apparent. Above 150 ft., the measurements show the wind velocity and direction of the air above the stacks. The observed variation in the velocity of the wind is characteristic of light winds under turbulent conditions.

TABLE 2.—MEASUREMENT OF WIND VELOCITY WITH HOT-WIRE ANEMOMETER

Height, ft.	Wind Velocity, miles/hr.	Wind Direction	Remarks
100	3.4	W	Below the smoke path
100	4.2	W	
100	3.6	W	
150	5.6	W	Lower edge of smoke
150	8.0	W	
150	6.8	W	
175	7.0	WSW	Upper edge of smoke
175	8.0	WSW	

By measuring four meteorological elements, wind velocity, wind direction, lapse rate, and humidity, a better understanding of the dispersion of the contaminants from various sources can be obtained. In locations where the topography is irregular, these observations must be made at the actual plant site.

Path of Aerosols at Low Altitudes. On level terrain, it is not difficult to calculate the path of an aerosol in the effluent gases from a stack. Equations for the diffusion of gases, aerosols, and particles have been presented by Bosanquet and Pearson (*1*) and Sutton (*10*). Johnstone (*6*) has calculated the percentage of particles of a given size which will reach the ground at various distances from the base of the stack under several meteorological conditions. When a plant is located near intersecting valleys, the calculation for the path of the aerosol is much more difficult. It may be found easier to simulate the path of aerosols, in the field, from stacks of various heights than to calculate them.

Use of the Kytoon technique simplifies this problem. If a source of smoke is raised to various altitudes by a Kytoon, the path of the smoke may be followed visually and photographically. Such a smoke trace is shown in Figure 7. A standard smoke grenade was raised to the desired altitude and fired electrically. The path of the chemical smoke has been found to follow closely that of the industrial smoke at the same altitude, after the industrial smoke lost its thermal and dynamic velocity heads. In this way, the effect of building stacks of various heights at a particular plant can be predicted for various meteorological conditions.

This technique, then, gives industry a means for determining the extent of the dispersion of air contaminants under various conditions above existing plants, or it may be used to secure this information even before the foundation of the plant has been dug.

Summary

The determination of the concentrations of contaminants in the air at various low altitudes and controlled positions over industrial and metropolitan areas is important in understanding the dispersion potential of the atmosphere. Of equal importance is the determination of the meteorological elements at various altitudes in this earth-bound contaminant layer.

Fig. 5. Electrostatic precipitator held in sampling position by nylon cord to kytoons. Cables bring necessary voltages from ground level.

Literature Cited

1. Bosanquet, C. H., and Pearson, J. L., *Trans. Faraday Soc.*, 32, p. 1249 (1936).

2. Charmbury, H. B., Pennsylvania State College, "The Use and Limitation

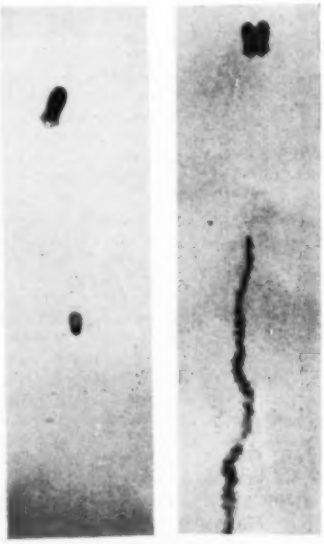


Fig. 6 (left). Wiresonde for measuring temperature, humidity, or wind velocity, supported by a kytoon.

Fig. 7 (right). Trace from a smoke grenade elevated to 375 ft. by kytoons.

of the Midget Impinger for the Evaluation of Aerosols," presented U.S.T.C.A.P., Washington, D. C. (May 3, 1950.)

3. Gerhardt, J. R., University of Texas, "The Coefficient of Eddy Transfer," presented *Am. Meteor. Soc.*, St. Louis, Mo. (Jan. 4, 1950).

4. Hewson, E. Wendell, and Gill, Gerald C., *U. S. Bur. Mines Bull.* 453, Part II, p. 63.

5. Huss, P. O., and Portman, D. J., University of Akron, D.G.A.I. Report 149 (Jan. 19, 1950).

6. Johnstone, H. F., and Roberts, M. H., *Ind. Eng. Chem.*, **41**, p. 2417 (1949).

7. Mossman, C. A., Lundholm, J., and Brown, P. E., Oak Ridge National Laboratory, Report 556.

8. Schrenk, H. H., and Brown, Carlton E., *U. S. Bur. Mines, Repts. Invest.* 4568 (December, 1949).

9. Smith, M. E., Brookhaven National Laboratory, "The Forecasting of Micro-Meteorological Variables," presented *Am. Meteor. Soc.* at St. Louis, Mo. (Jan. 4, 1950).

10. Sutton, O. G., *Proc. Roy. Soc.* (London), **135**, Section A, p. 143; Sutton, O. G., *Quart. J. Roy. Meteor. Soc.*, **73**, p. 426 (1947).

Discussion

Donald V. Ross (Tennessee-Eastman Co., Kingsport, Tenn.): Could you give us a rough idea of the relative efficiencies of impingers versus electrostatic precipitators for the determination of particulate matter; and the relative efficiencies of impingers versus the Thomas autometer for the determination of gaseous pollutants?

H. P. Munger: The Bureau of Mines has run some extensive comparisons between the midget impinger and the Greensburg-Smith impinger. In general, the work has indicated that the midget impinger is about as efficient and as satisfactory for most forms of sampling as the Greensburg-Smith impinger. However, it has the obvious disadvantage that you are sampling a smaller amount of air and for that reason if there is any variation in the concentration you may run into trouble. Other than the amount of air, I believe that the efficiency of the two types of impingers is about the same. There are two principal objections to the impinger-method type: one is that if the particles are particularly large it is possible that as they impinge on a solid surface they may break, the number of particles would be increased and the size of the particles would be decreased.

A second difficulty is the fact that the impingers are not nearly so efficient in collecting the very fine particle sizes as the electrostatic precipitator.

The electrostatic precipitator is not suitable for collecting sulfur dioxide and of course the autometer was designed primarily for this purpose. With the midget impinger a technique has been developed for its use in sampling for sulfur dioxide. It involves bubbling a gas through iodine and we have found it necessary to make a correction for the amount of iodine which would be sublimed. A correction of this kind always puts a certain amount of doubt onto the results of the test. For extremely small particles, the electrostatic precipitator is by far the best method of sampling. The Thomas autometer, of course, is best for SO_2. The midget impinger has its application where the particles are in a particular size range. It was originally designed in connection with silicosis work. In measuring the number of particles in a size range between 1 and 10μ, the impingers do a good job. Outside of that range they have certain definite limitations.

F. C. Roop (Standard Oil (Ind.), Chicago, Ill.): You mentioned the use of motion pictures for the smoke trace. What time interval did you find appropriate between exposures and what kind of equipment did you find necessary for this work?

H. P. Munger: The work which we have done so far has been with an ordinary standard 16-mm. Eastman camera using a yellow smoke trace. The best results were obtained when using a red filter. That has to be determined by experience, because to no small extent, the appearance of a smoke trace will depend upon the background. We have found with certain filters, that if we have a fly ash background, you can see the yellow smoke as light colored, but it will turn dark against the background of the sky. So, in each case it is necessary to determine experimentally just what is the best combination of filters and color of smoke depending upon the location and upon meteorological conditions. With a cloud background the filter you use would necessarily be different from the one you would use if you had a clear blue sky background.

W. C. Kroetz (Student, Ohio State University, Columbus, Ohio): In regard to this smoke trace equipment technique—you mentioned you could raise your smoke grenades to the proper altitude and take your pictures. You also mentioned you could correct for the velocity test of the gases. What relationship do you use, or correlation, or calculation, to decide the temperature effect of the gases? For example, if you have 700° F. gases emitting from the stack as against perhaps, the case of 400° F.?

H. P. Munger: The best way of averaging out the thermal and velocity heads is to compare the flow of the smoke from the smoke grenade, at various heights, to the flow of the smoke from the stack. In actual practice, a smoke plume ordinarily will fan out into a cone. If you were to fire your grenade at such an altitude that the smoke was at the top of that plume then you would know that you were at the maximum height to which the smoke was going.

If, on the other hand, you find you are interested particularly in the effect of smoke beating down to the ground, you are more interested in the minimum height of that cone. In that case, you would want to fire the grenades at such a position that the smoke would travel at the bottom of the smoke cone. Using that as your base line, raise your grenades 100, 200, or 300 ft. higher to determine what the effect of emitting the same gases from stacks at higher altitudes would be.

R. C. Kintner (Illinois Institute of Technology, Chicago 16, Ill.): Was the 12,000-volt potential on your electrostatic precipitator a pulsating direct current or an alternating one?

H. P. Munger: The 12,000 v. was direct current. We wondered how we were going to get 12,000 v. up in the air. The original idea was to use 110 v. and have a transformer at the precipitator. You then run into weight problems because everything connected with kite-balloon techniques revolves around weight. The curious part about it is that the insulation of ordinary radio wire, with polyethylene insulation, would stand 12,000 v. The wire was wound on a reel in order to be able to raise the electrostatic precipitator to a number of different heights. We found that 12,000 v. didn't arc across inside of the reel. But when we increased the voltage to 15,000 v. you could hear the current snapping across in between the various layers within the reel. The answer to that problem is obvious. If you have difficulty with arcing within the reel the only thing necessary is to have a different length wire for each one of your determinations so that the air would act as the insulator and you wouldn't use the reel—you would run out 300, 400 or 500 ft. or whatever increments you needed to make your determination, and use 15,000, 20,000 v. or almost any voltage within the limits of the insulation around the terminals.

(Presented at Forty-third Annual Meeting, Columbus, Ohio.)

CAST ALLOY REFERENCE SHEET

N. S. MOTT, Chief Chemist Metallurgist
The Cooper Alloy Foundry Co., Hillside, N. J.

ALLOY: HEAT AND CORROSION RESISTANT NON-HARDENABLE 18% CHROMIUM ALLOY.

APPLICATIONS AND REMARKS: The 18% chromium alloy contains enough chromium to make it a truly rustless composition; however, because of its low ductility and resistance to shock it is greatly limited as to use. It finds application in food processing, in handling nitric acid, and in rayon manufacture. Having good resistance to heat, oxidation, and hot sulfur gases, it is often used for rabble blades in ore roasting furnaces and for other high temperature applications.

DESIGNATIONS: AC1 CB-30; A1S1 442; SAE 60442; ASTM A-296-49T, Grade CB-30.

MACHINABILITY: This alloy is readily machinable due to its lack of ductility and toughness combined with a proper amount of hardness. Chips are short and brittle.

HEAT TREATMENT: The 18% chromium alloy is not hardenable but casting strains may be relieved by a process annealing heat treatment consisting of heating 1450° F. and holding for 2 hrs. followed by air cooling.

CHEMICAL COMPOSITION RANGE: C < .30%; Cr 18-22%; Ni < 2%; Si < 1%.

WELDABILITY: This alloy may be welded using either a rod of similar composition or a 25-20 type of rod. Welds are very brittle unless annealed. A preheat of 250-300° F. should be used. After welding cool to 150° F. or lower, heat to 1450° F. and hold for 4 hrs., then air-cool. When heated above 1800° F. grain growth occurs which cannot be refined by heat treatment, so the welding operation should be as brief as possible. Differences in thermal expansion preclude use of 25-20 welding rod for applications at high temperatures.

MECHANICAL AND PHYSICAL PROPERTIES:

Tensile Strength, 1000 lb./sq.in.	99	Melting Point	2710-2730 F.
Yield Point, 1000 lb./sq.in.	75	Specific Heat (B.t.u./(lb.)(° F.)) 32-212° F.	0.11
Elongation, %	4	Thermal Expansion (× 10⁶ in./(in.)(° F.)) 32-212° F.	5.7
Reduction in Area, %	4	Thermal Conductivity (B.t.u./(hr.)(sq.ft.)(° F./in.)) 32-212° F.	181
Brinell Hardness	217	Electrical Resistance (Ohms./cir. mil. ft.) @ 32° F.	402
Charpy Impact (Std. Keyhole ft.-lbs.)	2		
Mod. of Elasticity (× 10⁶ lb./sq.in.)	29		
Specific Gravity	7.61		

CORROSION RESISTANCE

ACIDS	
Acetic 5%, 70 F	E
Acetic 5%, boiling	E
Acetic 80%, 70 F	G
Acetic 80%, boiling	G
Acetic Glacial, 70 F	G
Acetic Glacial, boiling	N
Benzoic 5%, 70 F	E
Boric 5%, 176 F	E
Chromic 10%, 70 F	F
Chromic 10%, boiling	P
Chromic 50%, boiling	N
Citric 5%, 70 F	E
Citric 25%, boiling	F
Citric 50%, boiling	N
Formic 5%, 70 F	G
Hydrochloric 1%, 70 F	N
Hydrochloric 1%, boiling	N
Hydrochloric, 5%, 70 F	N
Hydrochloric 5%, boiling	N
Hydrochloric 25%, 70 F	N
Hydrochloric 25%, 176 F	N
Hydrofluoric 40%, 70 F	N
Hydrofluoric 40%, 176 F.	N
Lactic 5%, 70 F	G
Malic, all temps.	G
Nitric all concs., 70 F	E
Nitric 65%, boiling	G
Oleic all concs., all temps.	G†
Oxalic 5%, boiling	F†
Phosphoric 10%, 70 F	P
Phosphoric 85%, 70 F	E
Phosphoric 85%, boiling	N
Stearic concentrated to 200 F	E
Sulfuric 2%, 70 F	N
Sulfuric 2%, 176 F	N
Sulfuric 2%, boiling	N
Sulfuric 5%, 70 F	N
Sulfuric 5%, 176 F	N
Sulfuric 5%, boiling	N
Sulfuric 10%, 70 F	N
Sulfuric 10%, 176 F	N
Sulfuric 10%, boiling	N
Sulfuric 78% (60° Be), 176 F	N
Sulfuric 93% (66° Be), 70 F	G
Sulfuric 93%, 300 F	N
Oleum, 70 F	F
Mixed Acids 57% H_2SO_4, 28% HNO_3, 176 F	F
ALKALIES	
Ammonium Hydroxide, all concs.	E
Calcium Hydroxide Sat., 70 F	E
Calcium Hydroxide Sat., boiling	F
Sodium or Potassium, Hydroxide, all concs., 70 F	E
Sodium or Potassium Hydroxide < 20%, boiling	E
Sodium or Potassium Hydroxide 30% boiling	F
Sodium Hydroxide, Molten, 600 F	N
NEUTRAL AND ALKALINE SALTS	
Barium Sulfide, 70 F	G
Calcium Chloride 5%, 70 F	F†
Calcium Sulfate Sat., 70 F	E
Magnesium Chloride 5%, 70 F	F†
Magnesium Sulfate 5%, 70 F	G
Sodium Carbonate, all concs., 70 F	E
Sodium Chloride 5%, 70 F	F†
Sodium Sulfate 5%, 70 F	E
Sodium Sulfide 5%, 70 F	F†
Sodium Sulfite 5%, 70 F	F
ACID SALTS	
Alum 10%, boiling	F†
Aluminum Sulfate 10%, 70 F	P
Ammonium Chloride 5%, 70 F	F†
Ammonium Sulfate 10%, 70 F	F†
Ammonium Sulfate 10%, boiling	P
Ammonium Nitrae, all conc., 70 F	E
Stannous Chloride 5%, 70 F	N
Zinc Chloride 5%, boiling	N
OXIDIZING ALKALINE SALTS	
Calcium Hypochlorite 2%, 70 F	P†
Sodium Hypochlorite 5%, 70 F	P†
Sodium Peroxide	E
OXIDIZING ACID SALTS	
Ammonium Persulfate 5%, 70 F	E
Cupric Chloride 1%, 70 F	N
Cupric Sulfate 10%, 70 F	E
Ferric Chloride 10%, 70 F	N
Ferric Sulfate, boiling	F
Mercuric Chloride 2%, 70 F	N
Stannic Chloride 5%, 70 F	N
WET AND DRY GASES	
Chlorine Gas Dry, 70 F	G
Chlorine Gas Wet, 70 F	N
Sulfur Dioxide Dry, 575 F	E
Sulfur Dioxide Wet, 70 F	F†
Sulfur Dioxide Solution, 70 F	P†
Sulfur Dioxide Spray, 70 F	N
Hydrogen Sulfide Dry	E
Hyrdogen Sulfide Wet	G
ORGANIC MATERIALS	
Acetone, 70 F	G
Acid Sludge (50% H_2SO_4), 200 F	N
Alcohol—Methyl and Ethyl	E
Aniline Hydrochloride, 70 F	N
Benzol, 176 F	G
Carbon Tetrachloride	E†
Chloroform	G
Ethyl Acetate, 70 F	G
Formaldehyde, 70 F	E†
Phenol 5%, boiling	G†
Refinery Crudes	P
Trichlorethylene, boiling	E†
PAPER MILL APPLICANTS	
Kraft Liquor	G
Black Liquor	G
Green Liquor	G
White Liquor	G
Sulfite Liquor, 176 F	P†
Chlorine Bleach	P†
Paper Makers Alum	F†
PHOTOGRAPHIC INDUSTRY	
Humid Atmospheres	E
Cellulose Acetate	P
Acetic Anhydride	F
Acetic Acid + 1% H_2SO_4	N
Developers	E
Solutions Containing SO_2	P
Silver Nitrate, 70 F	E
FERTILIZER MANUFACTURING	
$H_3PO_4 + H_2SO_4 + HF$	N
PICKLING OPERATIONS	
H_2SO_4 + Dichromate, 176 F	N
H_2SO_4 + Hcl, 176 F	N
CORROSIVE WATERS	
Acid Mine Water	F
Abrasive Acid Mine Water	N
Sea Water	G†
Brackish Water	G†
FOOD & ASSOCIATED PRODUCTS	
Brines	F†
Edible Oils	G
Fats	G
Fatty Acid Distillation	G
Fruit Juices	E
Ketchup	G†
Milk Pasteurizing	G
Vinegar and Salt, 70 F	F†

RATINGS:

E—Excellent resistance. 0.001 max. in. per year of penetration. Corrosion so slight as to be harmless.
G—Good resistance. 0.001-0.010 in. per year of penetration. Satisfactory service expected; at most a slight etch.
F—Fair resistance. 0.010-0.120 in. of penetration per year. Satisfactory service under specific conditions. Light to moderate attack.
P—Poor resistance. 0.120-0.480 in. of penetration per year. Satisfactory for temporary service only.
N—No resistance. 0.480 min. in. of penetration per year. Rate of attack too great for any use.
†—Subject to pitting type corrosion.

No. 2
(SECOND OF A SERIES OF TEN)

ROCHESTER MEETING September 16-19

Veterans' Memorial spans the historic Genesee River gorge in Rochester

A WARM and cordial invitation is extended to all to attend the Rochester meeting of the American Institute of Chemical Engineers, Sept. 16-19, at the Sheraton Hotel, Rochester, N. Y. Your hosts, the Rochester Section and the Institute's Technical Program Committee, have arranged an interesting program, embracing symposia on Industrial Photography, Plant Maintenance, and Chemical Engineering Education.

Rochester, a city with a metropolitan population of 450,000, is located on the south shore of Lake Ontario in western New York State. It is particularly suited to an A.I.Ch.E. meeting. Many of the familiar trade names on chemical plant equipment throughout the world have their origins in the Rochester area —Lightnin and Mixco mixers, Pfaudler Glass Lined tanks and process equipment, Taylor Instruments, Lapp Chemical Porcelain, Garlock gaskets, D.P.I. high vacuum equipment, and many others. Inspection trips have been arranged through several of these plants. These tours, coupled with the symposium on maintenance, should prove extremely valuable to operating engineers.

The photographic and optical industries are a prominent part of Rochester life. Eastman Kodak, Bausch and Lomb, Haloid, Bell and Howell, Du Pont, Ilex Optical, and Wollensak Optical are among the industry leaders that have given Rochester the title of "Photographic Capitol of the World." Process operations play an important part in all these industries—more than 70 per cent of the membership of the Rochester section are employed in these plants.

Because photography is becoming widely used as a production and engineering tool, an informative symposium on "Industrial Applications of Photography" will occupy an important spot in the technical program. The session will be supplemented by a plant trip through Eastman Kodak Co.'s huge Kodak Park plant and a visit to George Eastman House, the new world photographic center in Rochester.

The city is a center of fine chemical and pharmaceutical manufacture. It is the home of Eastman Organic Chemicals, Distillation Products Industries,

Committee chairmen—Left to right: Donald J. Kridel (Eastman Kodak Co.) Hotel; Earl W. Costich (Mixing Equipment Co.) Registration; Robert M. Jackson (Distillation Products Ind.) Transportation, and Eric J. Stettner (Eastman Kodak Co.) co-chairman, Finance.

Mrs. P. S. Barnes, chairman of the Ladies' Comm., and Albert Ackoff, general chairman (left), and Carl Gath, chairman of the Program Comm., discuss plans for entertaining the ladies at the Rochester meeting.

Article by I. Siller, The Pfaudler Co., and F. J. Newberg, Eastman Kodak Co.

Committee chairmen—Left to right: Ingales S. Bradley (Eastman Kodak Co.) Co-Chairman, Plant Trips; Fred W. Kunkel (Eastman Kodak Co.) Hospitality; James S. Bruce (Eastman Kodak Co.) Photographic Exhibit, and Eric K. McLean (Distillation Products Ind.) Public Relations.

Genesee Research Corp., R. J. Strasenburgh Co., and others. It is also the hub of a huge canning and food-processing industry, drawing on products of the rich farmland in the surrounding country. In all, the city is a center of diversified industry, with a total of 1,500 major manufacturing plants. All invite your inspection.

As an educational center, Rochester rates with the finest. The University of Rochester maintains an accredited chemical engineering course in its college of engineering, a college of arts and sciences, a school of music, and a school of medicine and dentistry. The editorial offices of the Journal of the American Chemical Society are located on the campus. The University is also the seat of chemical and medical phases of atomic research. Opportunity to view some of these facilities and participate in the Chemical Engineering Education Symposium should attract educational leaders from all over the nation to the Rochester meeting in September.

Other institutions for higher education in Rochester include the world-renowned Eastman School of Music, Rochester Institute of Technology,

(*Continued on page 23*)

A bird's-eye view of the city that awaits your visit.

SYMPOSIA

Monday Morning

CHEMICAL PLANT MAINTENANCE

D. E. Pierce, presiding

Maintenance Organization and Operation.—*Lyman G. Darling, engineering service division, Du Pont Co.*

Designing for Maintenance.—*Lester B. Woolfenden and Richard C. Thiede, General Aniline and Film Corp.*

Preventive Maintenance in the Chemical Industry.—*W. E. Chandler, Monsanto Chemical Co.*

Installation, Operation and Maintenance of Fluid Mixing Equipment. *Richard D. Boutros, Mixing Equipment Co.*

Tuesday Morning

INDUSTRIAL APPLICATION OF PHOTOGRAPHY

Carl H. Gath, presiding

Industrial Interest in Photographic Methods and Practices.—*Paul A. Barbee, Eastman Kodak Co.*

Photographic Organization Within a Chemical Industry.—*R. C. Kinstler,, Procter and Gamble Co.*

Industrial Photography as a Tool for Engineers.—*G. H. Gustat, Eastman Kodak Co.*

Some Startling Revelations in Industrial Photomicrography.—*C. S. Foster, Eastman Kodak Co.*

Wednesday Morning

CHEMICAL ENGINEERING EDUCATION

W. E. Gift, presiding

Accrediting Standards for Undergraduate Curricula.—*G. C. Brown, University of Michigan.*

Should There Be Two Undergraduate Curricula — Specialization and Fundamentals?—*J. H. Boyd, Columbia University.*

How Can Industry and Colleges Cooperate Better to Improve Chemical Education? —*W. T. Nichols, Monsanto Chemical Co.*

Technical Sessions

Wednesday Afternoon

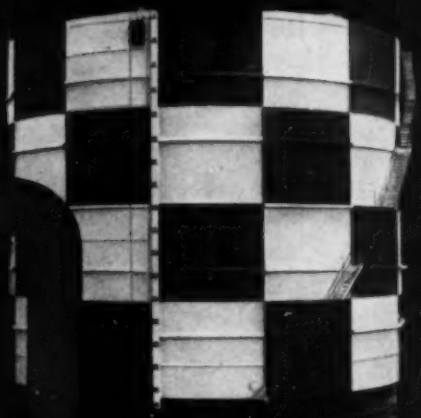
Solvent Drying.—*Richard J. Mitchell, California Research Corp., Richmond Laboratories.*

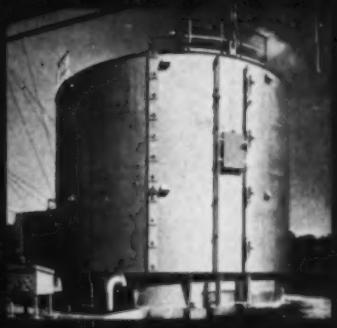
Drying of Air in Fixed Beds. —*L. C. Eagleton and Harding Bliss, Yale University.*

Adiabatic Humidification of Air with Water in a Packed Tower.—*S. L. Hensel, Jr., and Robert E. Treybal, New York University.*

Mass Transfer in a Fluidized Bed.— *Ju Chin Chu, James Kalil, and William A. Wetteroth, Polytechnic Institute of Brooklyn.*

Metering Liquid Sulfur.—*James R. West, Mellon Institute of Industrial Research.*





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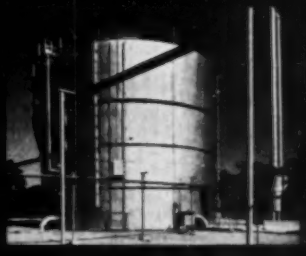

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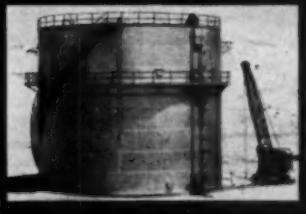

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Converted from old style!

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Operates at pressures up to 20" of water. Gas tightness and impermeability of Wiggins dry seal proved in 15 years' service under actual operating conditions. Ask about converting your present gasholders to Wiggins principle.

WRITE FOR NEW BULLETIN WG-22
OR REFER TO BUILDER'S COMMITTEE REPORT, May, 1951, AMERICAN GAS ASSOCIATION

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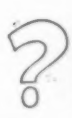

2 Any acceptable alternates in type, finish, composition, and size.

3 A brief, informative description of your intended fabricating methods.

4 A description of the end-use, exact as to product and its service.

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URGES NEW ENERGY SOURCES FOR U. S.

The consumption of energy in the United States by the year 2000 will be equal to the current consumption of the entire world, or about 25 trillion horsepower-hours per year, G. W. Gleeson, dean of the School of Engineering and Industrial Arts at Oregon State College, declared last month before The American Society of Heating and Ventilating Engineers meeting in Portland, Ore. In the light of this, he urged that consideration be given to the development of the continuous sources of energy, water power, energy from vegetation (directly and indirectly), solar energy, wind power, earth heat, tidal power, tropical waters and the heat pump.

With the exception of hydroelectric power, our energy now comes from discontinuous sources, the fuels of which are finite in amount, he said. Although there are ample and available sources of energy to provide for our immediate requirements, he pointed out, the cream has already been consumed, and within the coming century, the fuel situation as we now know it will not exist. He listed among the discontinuous sources of energy, coal, petroleum, oil shales, natural gas and atomic energy.

Dean Gleeson said atomic energy is unique in that it is the only energy source in the discontinuous category which does not depend upon a fossil fuel, and accordingly uses the only fuel which is inorganic. He said energy produced by nuclear fission has developed the concept of a practically inexhaustible energy which is certainly not true. As with any energy source it is dependent upon a fuel supply in the form of fissionable material which like other fuels is definitely limited in amount, he emphasized.

Even the most optimistic estimates lead to the conclusion that nuclear fission as a source of energy will be a highly specialized one having definite limitations and a probable transitory existence comparable to that of petroleum, Dean Gleeson said. He called for periodic inventory of our energy resources and urged that our fossil fuels be conserved by substitutions of one discontinuous source for another and continuous sources for the discontinuous ones.

"In addition to development of new sources of energy, we have much to accomplish by way of improvement in use of currently developed sources through higher efficiencies of utilization, transport, and conversion," he said.

Other points made by Dr. Gleeson were:

1. In the interest of future generations as well as in the interest of true conservation,

(*Continued on page* 42)

The new construction at the Cherokee plant of Merck & Co., Inc., at Danville, Pa., shown above, is for expanded production of vitamin B12, penicillin, niacin and Cortone, the Merck brand of cortisone. Six of the 12 new buildings have been completed. The company has been using some of the buildings of the former Cherokee Ordnance Works since the start of operations in August, 1950, and the remainder of the buildings are being kept in stand-by condition for meeting possible Army requirements. The buildings portion of this several-million-dollar project will be completed by September of this year but the rest of the time will be needed for installing some 1400 items of complex equipment and the time-consuming processes required for the manufacture of cortisone.

Manpower Chief Concern of A.S.E.E.

MORE than 1800 teachers of engineering and science met late in June at East Lansing, Mich., for the 59th Annual Meeting of the American Society for Engineering Education. Michigan State College was headquarters for the conclave, and the chief problem concerning the educators was the supply of engineers.

Dean S. C. Hollister, newly elected president of the A.S.E.E. and M. M. Boring reported to the group on the current need for engineers and scientists and stated that a June, 1951, survey of the needs of 378 companies and government agencies showed that about 80,000 engineers are needed now, exclusive of the needs of the military.

The report went on to state that "when the current graduating class of 38,000 is absorbed, there is still an unfilled demand for 42,000 engineering graduates. However, a recent survey of the 1951 class of engineering graduates showed that the military, through ROTC and reserve programs and through the selective service system, will syphon off about 19,000 engineering graduates. The actual unfilled demand will then be for more than 60,000 engineers." The report stated that "the urgent need for engineers cannot be met through the current sources of supply."

It also predicted that "the 1952 graduating class will only be about 26,000—1953 about 17,000—and 1954 about 12,000."

The report gave the results of a telegraphic survey conducted by the Engineering Manpower Commission of Engineers' Joint Council in June, 1951, and showed that for engineers, 378 companies needed a minimum of 21,964 for 1951; they had received acceptances from 9,838 engineers; the total number of 1950 graduates hired by these companies was 12,161, and the best estimate of total graduate engineers in their employ amounted to 127,972. None of these figures includes the military needs of the Department of Defense, or the military needs of the Atomic Energy Commission.

Another address which pointed up the manpower situation was made by Dr. Eric A. Walker, executive secretary of the Research & Development Board, who said that the Department of Defense work requires nearly half the nation's research engineers and scientists; that these needs will rise to 65% within the next year. He also revealed in his talk that military research and development in 1951 cost more than seven times the amount of money expended on our entire national research and development effort in 1940.

Concerning manpower, he stated "the nation's scientific and technical manpower resources now total some 575,000

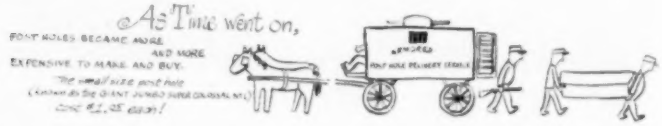
(*Continued on page* 43)

POST HOLES STANDARDIZED BY A.S.A.

American Standards Association, Inc., has issued a bulletin, well illustrated, to point up the dramatic struggle of Digby Holeston Postlethwaite and his early struggles at the beginning of this century, to standardize post holes. The efforts of the American Standards Association in bringing about a cooperative effort on the part of posthole designers, material suppliers, shippers, distributors, and sellers, plus the biggest users of post holes, including the railroad, telephone and telegraph companies, are all dramatically told in this bulletin illustrated by Tom Ross.

The crisis engendered during a war when government engineers decided that post holes adapted as ready-built foxholes for infantry, should have seven sides instead of six, is also well thought out and presented to the reader all in an attempt to bring home to American industry the need for standards in all our manufacturing operations, as well as the advantage to accrue from such a course of action.

Copies of the booklet may be obtained by writing to the American Standards Association, Inc., 70 East 45th Street, New York 17, N. Y.



CONFERENCE ON INDUSTRIAL EXPERIMENTATION

The Second Conference on Industrial Experimentation sponsored by the department of industrial engineering of Columbia University, New York, will be held Sept. 17-21, 1951, on the Columbia campus. This conference is designed to bring to those engaged in industry and research some of the latest developments in modern statistical methodology which are pertinent to the design and analysis.

Among the full-time instructors will be Prof. C. Daniel, department of chemical engineering, Polytechnic Institute of Brooklyn.

The fee for the Conference, including all books and supplies and all lunches and dinners at the Men's Faculty Club is $150.

Inquiries or requests for brochures and applications should be addressed to Prof. S. B. Littauer, department of industrial engineering, Columbia University, New York 27, N. Y. The enrollment is limited to 50.

BRAZIL SUBSIDIARY FOR MONSANTO

Monsanto Chemical Co. last month formed a new subsidiary company in Sao Paulo, Brazil.

Charles Allen Thomas, president of Monsanto, said that Monsanto S. A. Produtos Quimicos e Plasticos has been formed by Monsanto and a group of Brazilian interests.

The new company will construct plants probably in the vicinity of Sao Paulo for the manufacture of vinyl chloride monomer and Ultron polyvinyl chloride resins and compounds.

The Brazilian company will be under the general supervision of Monsanto's foreign department. The technical management of the new plant will be under the direction of the company's plastics division.

M. R. I. RESEARCH VOLUME UP

Total research volume during the first six months of the fiscal year shattered all previous records, it was reported by Dr. Charles N. Kimball, president of Midwest Research Institute, to the semi-annual meeting of the Board of Governors in Kansas City.

Comparisons with similar periods last year revealed as much as 50% increase in dollar volume for the seven-year-old institution. On an annual basis the figures will approach the million-dollar mark.

Another result of the expanded scope of Institute operations was the formation of a Chemical Engineering division, to be operated in addition to the already-existing Physics, Engineering and Chemistry divisions.

CHEMICAL EXPOSITION IN NOVEMBER

This year the 23rd Exposition of Chemical Industries will be held in New York City, Nov. 26 to Dec. 1, according to Charles F. Roth, manager of the exposition and president of the International Exposition Co.

Roth, in the announcement, stated that all available exhibit space on the exposition floors of the Grand Central Palace has been made available, and advance space reservations and applications indicate an exceptionally heavy concentration this year. The associate manager of the show is E. K. Stevens.

CORNING TELLS BANTING STORY

Corning Glass Works, Corning, N. Y., recently published the seventh booklet in its series on famous names in chemical history, covering the life of Frederick Banting, medical scientist who discovered the link between diabetes and insulin.

Corning started the famous name series about ten years ago, and the pamphlets, which are written in simple language for the nontechnical, is available to those who request them. They are designed primarily for high school and college students.

Others in this series are on the accomplishments of Henry Cavendish, John Dalton, Antoine Lavoisier, Father Nieuwland, Louis Pasteur, and Joseph Priestley. For copies, address P. M. Reynolds, advertising manager, Corning Glass Works, Corning, N. Y. (Technical Products Division).

COMMERCIAL SOLVENTS PLANS NEW PROJECT

Commercial Solvents Corp. has been granted a Certificate of Necessity amounting to $20,458,000 to expand its ammonia and methanol production facilities at Sterlington, La., it was announced by J. Albert Woods, president.

The construction, which will start immediately, will double the present production capacity of both ammonia and methanol now being produced at Sterlington by high-pressure synthesis using natural gas. In addition, a new unit will be erected for making ammonium nitrate for use in the fertilizer trade.

The Certificate of Necessity provides for rapid amortization at 50% of the estimated cost of the new facilities. The project will be completed and in operations by January, 1953.

100TH MEETING ELECTROCHEMICAL SOC.

Detroit will be host to the autumn national convention of the Electrochemical Society, Oct. 10-12. This will be the Society's 100th convention. It is fitting that this 100th meeting will be in Detroit, since that city is celebrating its 250th anniversary. Convention headquarters will be the Hotel Statler in the Motor City.

The technical program, being assembled by the technical program committee in New York, will, to a major extent, treat of the electrolytic deposition phase of electrochemistry. The Plants' Visits Committee, under the chairmanship of Ben Davis, provides for special tours of the new Ford disposal plant at Monroe, the great Dow Chemical plant at Midland and the Detroit Chrysler plant.

ROCHESTER MEETING

(*Continued from page 18*)

Colgate-Rochester Divinity School, St. Bernard's Seminary, Nazareth College, and St. John Fisher College.

On the lighter side of life, Rochester has much to offer in the entertainment field. The city supports its own symphony orchestra, and the finest Broadway productions appear in its theaters. Excellent golf courses are available for those interested. Sight-seeing along the breath-taking Genesee River gorge and in the beautiful parks that have given Rochester the title of "The Flower City" is a treat you won't want to miss.

The program for the Rochester meeting has been designed with special emphasis on photography, maintenance, and education. A technical session and several interesting plant trips are included. The plant trips have been planned so that everyone interested can be accommodated. Each tour will be conducted on Monday afternoon, and again the following day. The companies being visited are prepared to welcome large groups of visitors. Visiting engineers won't have to sacrifice a symposium or technical session in order to include at least two visits in their schedule.

Here is the program as scheduled by D. E. Pierce, the technical program chairman, and the Local Committee on Arrangements:

Sunday, Sept. 16

Evening—Get-together party at the Sheraton

Monday, Sept. 17

Morning—Symposium on Chemical Plant Maintenance
Afternoon—Plant visits
Evening—Panel discussion on Engineering Manpower Shortage

Tuesday, Sept. 18

Morning—Symposium on Industrial Applications of Photography
Afternoon—Plant Visits
Evening—Cocktail hour, dinner, and visit to George Eastman House

Wednesday, Sept. 19

Morning—Round-table discussion on Chemical Engineering Education
Afternoon—General technical papers

In the past, Institute members have expressed a preference for a less "crowded" schedule at such meetings. The Rochester schedule has been carefully designed to eliminate conflicting events.

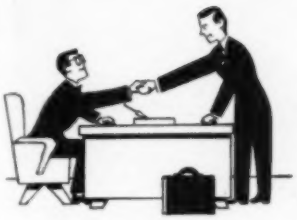
Sessions

Symposium: Maintenance

This session will be under the chairmanship of D. E. Pierce of General Aniline and Film Corp. Four papers are scheduled.

(*Continued on page 26*)

HOW PROCTOR RESEARCH MAKES POSSIBLE "GUARANTEED DRYER PERFORMANCE"



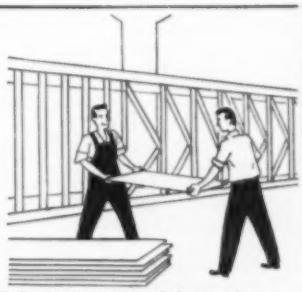
Your telephone call or letter to Proctor & Schwartz, Inc. will place you in immediate touch with a sales engineer who is thoroughly acquainted with the needs of your type of plant.

As a result of his interview tests will be conducted by the engineers in our research department where all of the latest equipment and data are available. You may even come to the lab yourself.

Based on test results, preliminary plans will be made by competent engineers to determine the size and kind of equipment needed together with approximate cost figures.

Having kept close touch with research and preliminary engineering the sales engineer will present recommendations to you. Together you will discuss these in terms of meeting your specific requirements.

Once your order is placed the equipment will be designed in exact detail so that the finished machine will meet your individual requirements—and perform exactly as guaranteed in the sales agreement.



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An air view of the giant $41,000,000 Hyperion sewage treatment plant designed to solve a beach pollution problem that has been harassing the people of the Los Angeles area for 25 years. Hyperion is the world's largest treatment works using a high-rate activated sludge process combined with sludge digestion, power generation, and fertilizer production. It generates all its own power and produces almost all its own fuel. The potential daily fertilizer production is 220 tons. The plant is designed for an average flow of 245 mgd., a normal dry weather peak flow of 350 mgd. and storm peak capacity of 420 mgd. Wrought iron is used wherever corrosion is a factor.

MANPOWER CONVOCATION IN PITTSBURGH

The Engineering Manpower Commission is planning an engineering manpower convocation in Pittsburgh, September 28, at the Stephen Foster Memorial Hall. The host organization will be the Engineers' Society of Western Pennsylvania. The purpose of the convocation is to inform the engineering profession about the critical shortage of the engineers, and the program of the Engineering Manpower Commission will be to invoke widespread cooperation in carrying out the program. The convocation is actually a pilot convocation at which industry and the profession in the Pittsburgh area will be represented, and to which representation from engineering groups throughout the country will be invited.

A brochure in package form containing the full talks at the convocation, plus all the releases of the Engineering Manpower Commission to date will be available.

The active cooperation of all the local sections of the parents societies in selecting the delegations that will represent their areas is sought. This will provide the framework for local groups to have similar convocations in their areas.

SOUTHERN CALIFORNIA

The July 17 meeting of this A.I.Ch.E. section was held in Carl's Restaurant, Los Angeles. The subject, "An Integral Method of Making Vapor-Liquid Equilibrium Calculations for Petroleum Fractions," was presented by W. C. Edmister, professor of chemical engineering, Carnegie Institute of Technology.

Reported by Gale S. Peterson

PHARMACEUTICAL CENTER FOR ARMOUR

Ground was broken for the new Armour Pharmaceutical Center late in June, and it was revealed that the company hopes to begin operations there within 18 months. The plant is being built on a mile-long, 175-acre tract just north of Bradley, Ill. The initial construction will consist of 11 buildings.

F. W. Specht, president of Armour and Co., and T. E. Hicks, vice-president in charge of the Armour Laboratories, officiated and pointed out that the Armour Laboratories have outgrown their present manufacturing facilities in Chicago, and that the increased demand for Acthar, insulin and other pharmaceuticals has made it necessary to set up new manufacturing facilities as soon as possible.

For the time being at least, pharmaceutical research will continue to be done at Chicago. As new and improved preparations are developed, actual production will be transferred to the Pharmaceutical Center.

DYNEL OUTPUT DOUBLED

Production of dynel staple fiber developed by Carbide and Carbon Chemicals Co., has been doubled, according to J. G. Davidson, president of this division of Union Carbide and Carbon Corp. The new plant addition in South Charleston, W. Va., originally scheduled for completion in July, attained full operation June 17, he reported.

Dynel, a chemical "warmth" fiber expected to become an important factor in the textile industry, is being produced now at a rate of several million pounds a year. The fiber is made from vinyl chloride, and acrylonitrile.

Carl A. Setterstrom, sales manager of the company's textile fibers department, reported at the same time on the uses of the new synthetic, stating that Dynel now has a wide range of uses —in apparel, home furnishings and in industrial fabrics. Important fundamental use studies have been completed and, while much remains to be accomplished, progress has been made in spinning, weaving, knitting, dyeing and finishing.

All spinnerets on the new production lines are now in full operation. The staple is produced in fiber deniers of 2, 3, 6, 12 and 24, and in standard staple lengths of 1½ to 6 in. Price of staple and tow is $1.25/lb. The fiber from the doubled production is committed to sustain the present diverse sales development program, Mr. Setterstrom stated.

SOLVAY EXPANDS CHLORINE PRODUCTION

The Solvay process division, Allied Chemical & Dye Corp., announced last month that it will shortly commence construction of a new mercury cell chlorine-caustic soda unit at its plant near Syracuse, N. Y. The new plant will involve an expenditure of $10,000,000 and will about double capacity of chlorine-producing facilities at Syracuse. It is estimated that 18 months to two years may be required to complete the project.

Solvay produces chlorine at its Baton Rouge, La., Huntsville, Ala., and Hopewell, Va., plants as well as at Syracuse. The Hopewell, plant uses salt and nitric acid as raw materials with sodium nitrate as a co-product and nitrosyl chloride as a by-product. At Solvay's other plants, chlorine and caustic soda are produced by electrolysis of salt brine. Just recently Solvay announced expansion of its Hopewell chlorine plant, in which a new chemical process developed by Solvay research will be employed. Under this process the nitrosyl chloride produced as a by-product in the existing chlorine plant at that location will be reacted with oxygen to produce chlorine and nitrogen tetroxide. The latter product will then be used to make additional nitric acid.

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ALCOA *Activated* Alumina has had a long and successful history of dehydration of liquids and gases. It has been particularly effective in the drying of propane and butane, the gases so important to the production of the new motor fuel, Liquefied Petroleum Gas.

Propane and butane, passed through beds of ALCOA *Activated* Alumina, are freed of their highly dispersed and dissolved liquid water, eliminating the problem of moisture in pipe lines and the hazards of frozen valves. Since ALCOA *Activated* Alumina is one of the few drying agents that will not shatter on contact with water, it is ideal for this operation. Moreover, it will not swell, soften or disintegrate . . . has high resistance to crushing, shock and abrasion . . . is non-toxic . . . non-corrosive . . . practically iron-free.

Years of use have proved ALCOA *Activated* Alumina to be one of the most effective and efficient desiccants available. Dew points as low as *minus* 100° F.—and even lower—have been obtained and under normal circumstances it can be used for an almost indefinite number of drying cycles.

If dehydration is a problem in your process, you will want to know more about this uniformly pure aluminum oxide. We'll gladly send you complete information. Write to: ALUMINUM COMPANY OF AMERICA, CHEMICALS DIVISION, 605H Gulf Building, Pittsburgh 19, Pennsylvania.

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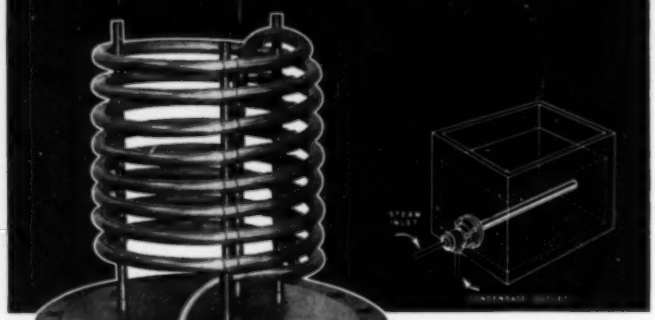
Heat Transfer Equipment



Above: Tantalum bayonet heater, the simplest form of heater. Left: Tantalum steam coil for rapid heating of contents of agitated kettle.

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Case history after case history testify to the fact that Tantalum heat exchangers not only effect savings which pay for the equipment in very short periods of time but, in the long run, give economies in maintenance which appear as big black profit figures.

How is all this made possible? By the very nature of the metal from which the heaters are made . . . tantalum. Tantalum combines the physical properties of steel with the chemical properties of glass, giving it three important qualities. 1. Speed in heat transfer. 2. Acid proof—for most acid solutions and corrosive gases or vapors. 3. Freedom from thermal shock. The results . . . the heaters heat faster, saving time, fuel and space—have a long life expectancy—give freedom from product contamination due to corroded equipment. Single bayonet-type Fansteel Tantalum Heaters are standard. Multiple bayonet and shell and tube type heat exchangers are designed and built to specifications.

USE TANTALUM WITH ECONOMY for most acid solutions, corrosive gases or vapors; not with HF, alkalis or substances containing free SO_3.

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Acid Proof

TANTALUM

CHEMICAL PLANT EQUIPMENT

ROCHESTER MEETING

(Continued from page 23)

Symposium: Industrial Applications of Photography

Carl H. Gath of Eastman Kodak Co. will serve as leader in this session. Four discussions to point up the importance and growing use of photography as a tool for industry will be presented.

Symposium: Chemical Engineering Education

This round-table discussion will be under the direction of W. E. Gift of Holston Defense Corp. It promises to be of interest to all engineers and supervisors in chemical industries. The three discussion topics and their leaders are listed on page 18.

The seminar on chemical engineering education will help to develop comment and advice on how to improve the educational program for chemical engineers. But because of the present alarming and critical shortage of chemical engineers, a special panel discussion, "The Engineering Manpower Shortage: What We Can Do About It." has been scheduled for Monday evening. Carey H. Brown, chairman of the Engineering Manpower Commission of the Engineers Joint Council, will lead this important discussion. Mr. Brown is manager of the engineering and manufacturing services division at Eastman Kodak Co.'s Kodak Park plant.

Plant Trips

To add interest to the program, five plant visits have been arranged. All trips are scheduled for both Monday and Tuesday afternoons.

Trip 1—Eastman Kodak Co. (Kodak Park Plant). Kodak Park is Kodak's largest manufacturing unit, devoted largely to the manufacture of photographic films, papers and chemicals. Departments to be visited include: roll film, silver nitrate, dope, distilling and potassium ferricyanide.

Trip 2—Combination Tour of Mixing Equipment Co. and Taylor Instrument Companies.—Taylor manufactures instruments for indicating and controlling temperature, pressure, flow level and humidity. Visitors will see tube system assembly, synchronization of control components, and testing and calibration of pressures and control manufacture of mercury in glass thermometers. Mixing Equipment Co. produces process-designed agitation equipment for fluids. This plant houses the complete engineering, research and production facilities of the world's largest manufacturer of mixing equipment. The modern research laboratory includes newest equipment for agitation research, including an electronic strain gauge, torque recorder, viscous and pilot plant equipment.

Trip 3—Garlock Packing Co.—Garlock manufactures mechanical packings, oil seals, molded rubber goods, rubber expansion joints and other industrial items. The production area includes a complete rubber

plant, a large textile plant, a new plant for impregnation of fiber sheet and continuous web, and a plastics department.

Trip 4—Pfaudler Co.—Glass-lined and alloy steel fabrications are Pfaudler's specialties. Among the first companies in the United States to build welded steel vessels, Pfaudler has pioneered in the welding of all types of materials by various methods. Visitors will receive a complete tour of production facilities.

In the Technical Session scheduled for Wednesday afternoon, a variety of papers will be presented.

Photographic Exhibit

In addition to this varied program, J. S. Bruce of Eastman Kodak has arranged a photographic exhibit open to all members and their companies. The exhibit falls into two classes: (1) photographs as an aid in engineer report writing, and (2) functional photographs for design, research and development. Members are urged to submit one or more entries to this exhibit (see page 13, July, 1951, "C.E.P." for details).

Ladies' Program

An attractive program for the ladies is another highlight of the Rochester meeting. Mrs. P. S. Barnes and her committee have arranged the following series of activities:

Sunday, Sept. 16
Evening—Get-together party

Monday, Sept. 17
Morning—Tour of Kodak Park Works
Luncheon—At the Rochester Club
Afternoon—City sight-seeing tour
Tea and fashion show at the Sheraton Hotel

Tuesday, Sept. 18
Morning—Tour of Memorial Art Gallery and Bausch Museum
Luncheon—At Oak Hill Country Club followed by bridge and canasta
Evening—Cocktail hour, dinner and visit to George Eastman House

Wednesday, Sept. 19
Morning—Tour of Fanny Farmer Studio
Luncheon—Sheraton Hotel
Afternoon—Open

Come to the Rochester Meeting in September. The city is easily accessible—passenger service is offered by four railroads and three airlines. Rochester is an overnight train ride or a short plane trip for three quarters of the population of the United States. A motor trip to Rochester would be stimulating from almost any direction, with the city near New York's beautiful Finger Lake region, Niagara Falls, the Adirondack Mountains and the Thousand Islands.

The program is varied. The appeal is wide. The Rochester Section, and the city at large, invite you to three days of entertainment, fellowship and helpful education.

(The End)

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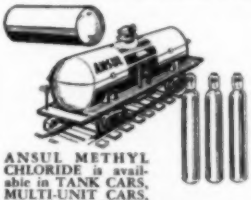

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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

Research Is Big Business

Review of Current Research and Directory of Member Institutions, American Society for Engineering Education. Engineering College Research Council, Room 7-204, 77 Massachusetts Ave., Cambridge 39, Mass. (1951) 244 pp. $2.25.

RESEARCH is a huge business not only for industry but, as this present volume proves, for universities as well. The 1951 edition of the Review of Current Research, is published by the Engineering College Research Council of the A.S.E.E. and outlines the policies and activities of engineering research in 91 colleges and universities, all members of the Engineering College Research Council.

Dr. Gerald A. Rosselot, director of the State Engineering Experiment Station at Georgia Institute of Technology is chairman of the Research Council and is greatly responsible for the present volume.

The details of the 5,200 engineering research projects which represent an annual expenditure of more than $50.5 million dollars, are included in this volume which, in addition, gives the complete research titles, the names of responsible research administrative officers in each school, a digest of policies which governs research projects and contracts at each institution, number of personnel engaged in these activities, annual expenditures, and special conferences and short courses of interest to research workers.

The research is broken down into major fields such as chemical engineering, civil, electrical, aeronautical, etc. The index lists alphabetically the subjects of the research projects and covers 4000 entries.

Problems and Solutions for Novices

Liquid Extraction. Robert E. Treybal. McGraw-Hill Book Co., Inc., New York, N. Y. (1951) 422 pp. $7.50.

Reviewed by Karl H. Hachmuth, Research Planning Board, Phillips Petroleum Co., Bartlesville, Okla.

A BOOK worth purchasing. It will serve well as a text for a chemical engineering course in extraction and will be of value to the practicing engineer who wishes to improve his knowledge of the subject. For one who is familiar with the subject, the book can save much literature review time whenever a problem arises outside his specialized field.

Each method of calculation or estimation in the book is illustrated by solutions of well-chosen problems. This feature in a technical book is valuable to practicing engineers who are novices in the field or subject described. A student may go to his instructor for explanation of a method not understood but the practicing engineer may not have an experienced man available to answer his questions. Neither should he be expected to spend valuable time unraveling an obscure explanation. Illustrative problems are good answers to this situation.

A little less than the first third of the book is used to discuss the fundamental concepts (phase equilibria, diffusion and mass transfer) concerning extraction and to point out methods for predicting distribution of materials between phases when complete data are lacking. This section is well presented.

Methods for calculating liquid-extraction processes are discussed in the next third of the book. This part is a good review of published methods but it gives more space than seems necessary to graphical methods of solution which, after all, can be applied rigorously to few industrial separations. It is unfortunate the author did not develop the "absorption factor" (called in the text "relative extraction efficiency") method further because this method can be extended to cover any number of components. The results may not be mathematically exact in all cases but, in view of the other uncertainties involved, are frequently good enough for practical purposes.

Slightly less than a quarter of the book describes various types of extraction equipment. Published data, mostly from small-scale experimental units, concerning performance of equipment are adequately reviewed but the reader soon discovers that the complete answer for his problem is not available. This is no criticism of the book but rather reflects the undeveloped state of knowledge concerning extraction processes.

The final chapter of the book describes various better-known extraction processes now used by industry (mostly the petroleum refining industry).

Leads For Market Analysts

Market Research Sources. Lois E. Randall and Dorothy M. Sharpnack, Marketing Division, U. S. Dept. of Commerce (Domestic Commerce Series No. 20), Supt. of Documents, U. S. Government Printing Office, Washington 25, D. C. (1950) 261 pp. $2.25.

Reviewed by M. C. Molstad, Professor of Chemical Engineering, University of Pennsylvania, Philadelphia, Pa.

THIS is the ninth edition of this valuable compilation, the eighth having been issued in 1949 and the first in 1926. It has been prepared "as an aid to sales executives and market analysts in locating sources of prepared data useful in measuring market potentials, setting sales quotas, selecting distribution channels, planning advertising campaigns, and adapting products and plans to present conditions and future prospects."

More than one third of the book is devoted to sources of information available from the Federal Government, and of this the most extensive in coverage is for the Departments of Agriculture and Commerce. While these provide a large fraction of the material useful in the chemical industry, many valuable references are found in the publications of other departments as well as such agencies as the Tariff Commission. Other interests than marketing are served incidentally; for example, data on fuels and power issued by the Federal Power Commission are of value in studies of plant location. Emphasis is on publications issued in recent years and on statistics which are regularly issued monthly or annually.

OMISSION

Fluid and Particle Mechanics reviewed in July, 1951, issue of *Chemical Engineering Progress*, page 24, is published by University of Delaware, Newark, Del.

Books Received

Galvanizing (Hot-Dip). Third edition. Heinz Bablik. John Wiley & Sons, Inc., New York, N. Y. (1951). 502 pp. $10.00.

An Introduction to the Chemistry of the Silicones. Second edition. Eugene G. Rochow. John Wiley & Sons, Inc., New York, N. Y. 213 pp. $5.00.

(*More Marginal Notes on page* 48)

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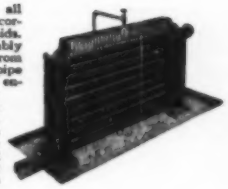

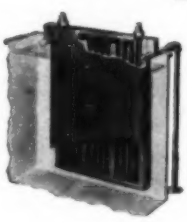

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E. which states:

Election to membership shall be by vote of the Council upon recommendation of the Committee on Admissions. The names of all applicants who have been approved as candidates by the Committee on Admissions, other than those of applicants for Student membership, shall be listed in an official publication of the Institute. If no objection is received in writing by the Secretary within thirty days after the mailing date of the publication, they may be declared elected by vote of Council. If an objection to the election of any candidate is received by the Secretary within the period specified, said objection shall be referred to the Committee on Admissions, which shall investigate the cause for such objection, holding all communications in confidence, and make recommendations to the Council regarding the candidate.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before *September 15, 1951*, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st St., New York 17, N. Y.

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S. R. Siemon, *Christchurch, N. Z.*

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William L. Ingmanson, *Appleton, Wis.*
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Michael Joffe, *Mt. Pleasant, Tex.*
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Richard A. Lorenz, *Davenport, Iowa*
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Don R. Mabon, *Portland, Ore.*
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(Continued on page 38)

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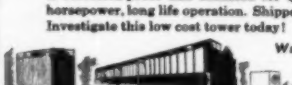

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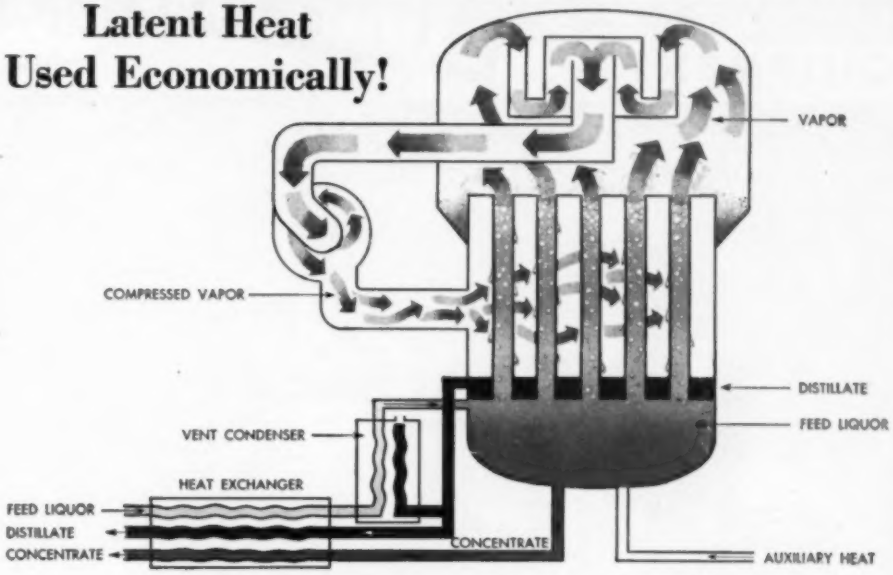

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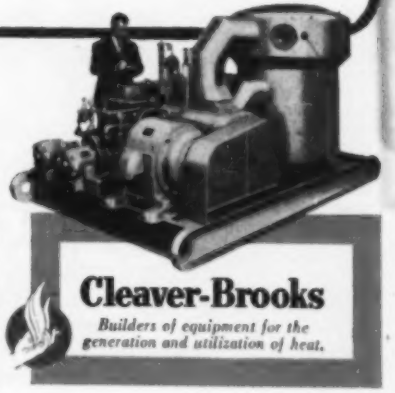

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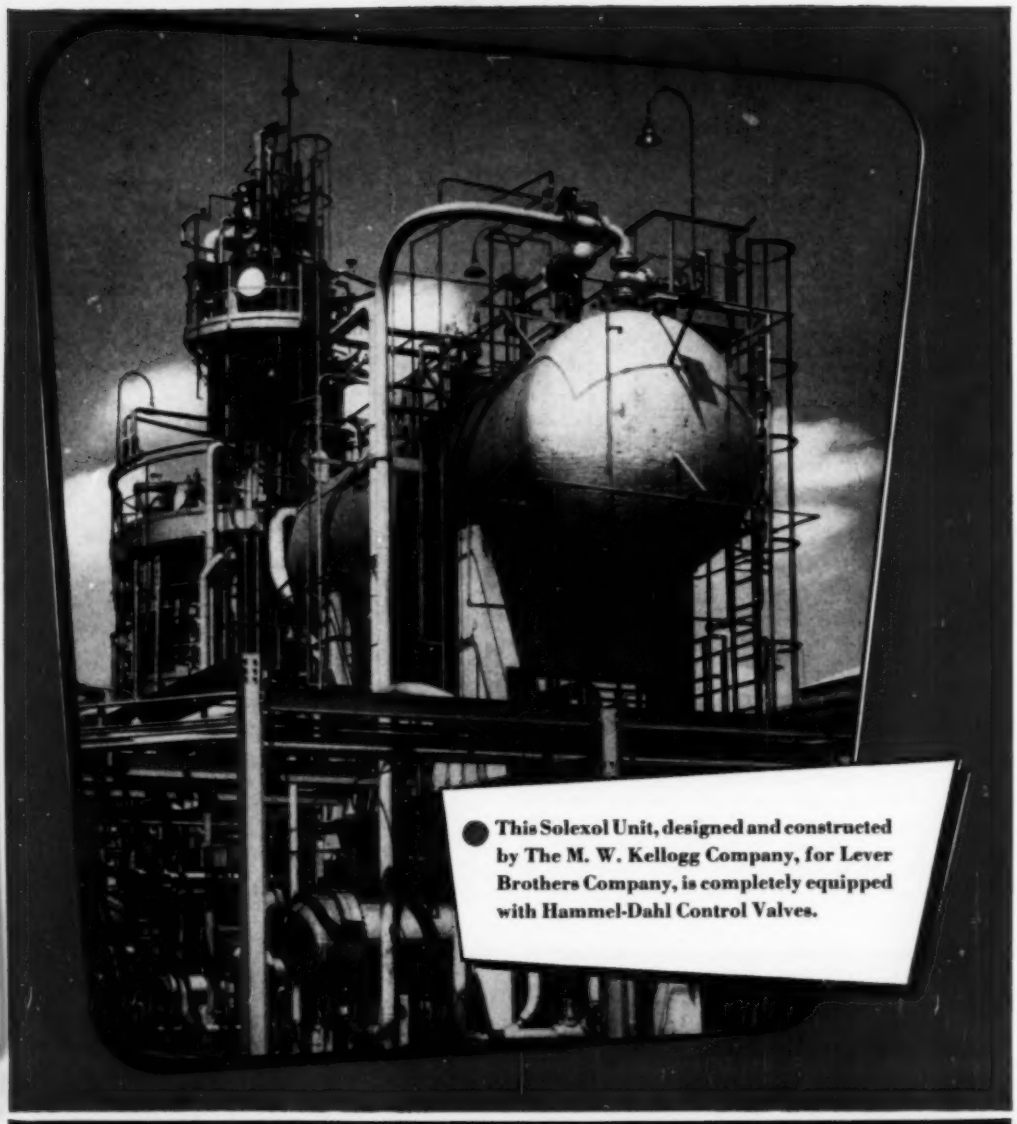

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Chemical Engineering Progress

DATA SERVICE

EQUIPMENT

1 • MEMBERSHIP INFORMATION. For chemical engineers wishing information on membership in the A.I.Ch.E., a booklet describing the organization and requirements for membership is available from the organization.

2 • VERTICAL MILLS. Vertical mills for the chemical process industry made by Enterprise Engine and Foundry Co. Brochure available describes the advantages of the vertical mill over horizontal types. Cutaway views show construction. 5-hp. size, 3600 rev./min., rotor 6 in. in diameter. Hammers are Stellited for longer life. Gravity feed and discharge.

3 • TUBULAR ELECTRIC HEATERS. For application of electric heat to liquids Martin-Quaid Co. tubular electric heaters. Description of units available, shows range of kilowatts for heaters, methods of installation and how used in open tanks and pressure vessels. Feature: low heat density.

4 • CHEMICAL FEED UNIT. For boiler feed water treatment, Neptune Pump Mfg. Co. is producing a tank, agitator, and pump, in one package. Adaptable to various control processes including automatic timing, flow, etc. Designed for pressures up to 1000 lbs., and capacities up to 15 gals./hr. Special chemical apportioning pump.

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6 • LINE BLIND VALVE. A new type line blind valve made by Hamer Oil Tool Co. features a simplified 3-bolt operation which one man can operate to release the spectacle plate. Valve is two-piece with telescoping hubs which slide one within the other to provide a fully enclosed chamber for the spectacle plate thus making the valve resistant to sidewise strains. Available in sizes from 2 in. to 8 in. Bulletin available.

7 • THERMOSTAT. For controlling temperatures up to 600° F. Smith Control & Instrument Corp. has a newly designed expanding tube thermostat. A stainless steel tube expanding member plus Invar strip as nonexpanding member. Adjusting screw permits setting control points up to 600° F. Three types available, sensitivity being 0.2° F. on a 1-amp. load.

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9 • LANDING MAT. A rubber and airfoam landing mat to cut destructive handling losses where heavy articles are unloaded produced by the Goodyear Tire and Rubber Co. Mat has a 2½-in. center of airfoam, top and bottom covering of rubber ¼ in. thick. For use in unloading drums, crates, barrels, packing cases, which should be protected from jars and heavy blows.

10 • AUTOMATIC TITRATOR. For laboratories, a Coleman instrument for fully automatic titration. Called Autotrator, performs automatically all steps. Titrant is delivered rapidly until end point approaches and then restricted. Controlled by an electrometer.

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12 • A.D.L. PRODUCTS. A booklet summarizing the work of Arthur D. Little, Inc., on the production, handling and storing of liquefied gases. Included are descriptions of helium cryostat, hydrogen liquefier, liquid oxygen generator, helium refrigerator, liquid oxygen pump, also non-contaminating gas-holder, air-cooler, high flux density electromagnet.

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chemicals, raw materials, synthetic compounds, food, etc., Patterson Foundry & Machine Co. has a new packaged drying unit. Consists of a rotary dryer with drive, screw feeder, air heater, fan, and dust collector. Continuous feed, variation in feed rate possible over a 3:1 range. Preheated air provided, automatic thermostatic control. Available in standard sizes from 2 to 3 ft. in diameter and in lengths from 10 to 24 ft. Various materials.

14 • VAPOR PURIFIER. To remove entrainment from vapors the Centrifix Corp. has a line of 1, 5, and 11-piece internal purifiers. In operation the purifier uses centrifugal and centripetal forces. Vanes tangentially located around the circumference of the purifier force vapors to release all entrained droplets. Three models are reported available for use in chemical, food and petroleum refining, etc. In addition to eliminating entrainment the units are said to be particularly valuable for reclaiming product otherwise lost in carry-over.

15 • CORROSION-RESISTANT FITTINGS. A new line of the Horace T. Potts Co. corrosion-resistant fittings to simplify installation and reduce costs of process piping jobs. In addition to standard tubing sizes, fittings are made for use with corrosion-resistant pipes in Schedules 5S, 10S and 40S. The company has newly designed insert flange a serrated insert in a carbon steel flange, a new aligning connector for use with standard pipe sizes which will enable different scheduled pipes to be connected, and a new low cost union.

16 • CHANGE TANK MIXER. Designed for thinning down, shading and tinting various batches of materials from 80 to 250 gal., a new change tank mixer has been designed by Charles Ross & Son Co. Features explosion-proof motor, 3 or 5 hp., direct power to stirrer arrangement. Motor and stirrer unit are capable of being raised and lowered.

17 • GLASS-WALLED FILTERS. A filter for use in laboratory and pilot plant work, with porous, stainless steel filter elements in glass-walled containers to permit full observation is announced by the Micro Metallic Corp. Unit can be ordered complete with a centrifugal pump or with a positive displacement pump mounted on an integral base. Eight sq. ft. of filter area in container 4½ in. in diameter and 40 in. long. Filter septum has 50% voids with pore sizes ranging from 5 μ to 165 μ.

18 • HYDRO-PNEUMATIC PUMP. For providing pressures up to 20,000 lbs./sq. in. The Aldrich Pump Co. has recently produced a hydropneumatic pump which uses normal plant air as the power medium. For use in testing tubing, valves, pressure vessels, etc.

19 • MANHOLE GASKETS. Asbestos gaskets for use on manhole or handholes where surfaces are rough or subject to considerable expansion, are products of Lawton H. Parsons. Used to hold a variety of chemicals, steam, etc. Standard sizes 3/16 in. thick, 7/16 in. wide and from 2½ in. 18 in. I.D. Special gaskets in larger sizes.

20 • CHAIN DRIVE. Morse Chain Co.'s engineers have developed a method of power transmission by chain drive that eliminates chordal action, the bumping and slapping caused by the chain riding over sprocket. The new drive incorporates a rocking sprocket joint. Take-up practically eliminated with the main advantage of the new drive being an increased power transmission for a given size. Thus a single unit may now transmit 5000 hp. at 6500 ft./min.; rotative speeds up to 3600 rev./min. 500 hp. are transmitted by a drive only 2 in. wide. A 6-in. drive will do the work formerly done by a 24 in. belt. Available in widths from 2 in.-12 in. Complete bulletins and details available.

21 • MOLDED SEALS. For use in extreme temperature ranges, The Parker Appliance Co. has a synthetic rubber O-ring and other molded seals. Resistant to non-fuel petroleum products, such as lubricating oils, it functions anywhere in the temperature range of —85 to +275° F. Gives satisfactory service with ozone.

22 • NEEDLE VALVE. Kerotest Manufacturing Co. describes its line of forged steel union bonnet needle valves for high pressures and corrosive services. Available in ⅛ in. to ¾ in. sizes for working pressures up to 4000 lbs. at 150° F. Forged from carbon steel, stainless steel, 12/14 chrome and 18/8 MO stainless steel. Conical seating surface.

23 • DOSIMETER. For measuring totally accumulated exposure to

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gamma or X-ray radiation, Arnold O. Beckman Inc. has designed and built a new dosimeter which may be clipped onto clothing when worn into dangerous areas. For use in scientific, commercial, medical, etc. installations where radiation is used. The range is 0 to 200 mr., sealed. Can be recharged.

24 • DISPERSATOR. Premier Mill Corp. is manufacturing a new mixing device, the Simplex Dispersator. It consists of a shaft-mounted cylinder rotating at a high speed. Centrifugal force speeds the product through narrow slots in the wall of the cylinder. A two-fold shearing effect, as the liquid passes through the slots, and also coming in contact with the slower mass of liquid in the mixing vessel. Designed for processing operations where propellers are ineffective. Used for speedy emulsification dispersion and intimate mixing.

CHEMICALS

25 • NAPHTHENATE DRIERS. Naftone, Inc., has a 16-page technical bulletin of Oronite naphthenate driers. Includes story behind the driers, a discussion of naphthenates vs. other types and the use of driers in oils and paints. Physical data given, comparisons with other metallic driers, specifications for a drier, and miscellaneous uses round out the book.

26 • "DIMETHOXY." Ansul Chemical Co. is now manufacturing dimethoxy tetraethylene glycol. Used as a selective solvent in the chemical field, it is miscible with both water and organic solvents with the solvent power alterable by dilution. Data sheet gives chemical and physical properties, uses, prices.

27 • POLYETHYLENE. From American Agile Corp. a folder on mechanical, electrical, thermal, and chemical properties of polyethylene. Data on the fabrication of equipment, parts, and pipe-line assemblies, etc. Mechanical, thermal, electrical resistance are all covered by tables and charts.

28 • ANHYDRIDES. Carbide & Carbon Chemicals Co.'s booklet on anhydrides describing all offered by the company. Uses, physical properties, shipping data, bibliography, and a section on the specification of anhydrides with a description of test methods. Covers acetic, propionic, butyric, carbic, and tetrahydrophthalic anhydrides.

29 • WOOD PRESERVATIVE. A compilation of specifications for the use of pentachlorophenol wood preservative, issued by state, federal and armed forces is available from Monsanto. Contains 60 specifications and an abstract of each. Is offered to engineers, etc., who use preservative treated wood.

30 • ARLECIN. Technical bulletin from Archer-Daniels-Midland Co. on soybean lecithin which covers properties, uses, grades, etc. Used in wall paints for which formulas are given, printing inks, caulking compounds, etc. All uses, formulations, etc., are shown.

31 • GEON RESIN. From B. F. Goodrich Chemical Co. a service bulletin on Geon resin 404, a high molecular polyvinyl resin which can be processed with plasticizing. Bulletin covers chemical resistance, physical properties, mechanical properties, processing methods, compounding, applications, etc.

32 • ELASTOMERS AND PLASTOMERS. Title of a publication from Foster D. Snell, Inc., describing services performed by the organization in plastic and rubber development. Describes the steps necessary in the development, evaluation, and trouble shooting.

33 • ALPHA METHYLBENZYLAMINES. A technical bulletin from Carbide & Carbon Chemicals Co. on three alpha methylbenzylamines. Presents in detail physical, chemical, and physiological properties of the materials. Potential applications as emulsifying agents, detergents, pharmaceuticals, etc.

34 • COPPER NAPHTHENATE. From Witco Chemical Co. a service report on the use of 8% copper naphthenate fungicide and preservative for cellulosic materials. Describes application, properties, specifications, etc.

35 • PRUFCOAT ALUMINUM. A new technical bulletin sheet on Prufcoat aluminum paint by Prufcoat Labs., Inc. Gives prices, plus some data on application.

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BULLETINS

36 • HARD HYDROCARBON IN RUBBERS. An extensive technical bulletin on "Witco M. R. (hard hydrocarbon) in Natural and Chemical Rubbers," has recently been published by the Witco Chemical Co. for rubber processors. The hydrocarbon is a blend of petroleum-derived asphalt and the compound is used as a filler, extender, or softener. The bulletin gives physical properties of hard hydrocarbon as well as effect of varying amounts in natural rubber for various cures, and compounds. Physical properties of the finished product for automotive tire treads, bicycle-tire treads, natural rubber tubing, etc. Second section on GRS. Final section on mixing and testing procedures.

37 • SURFACTANTS. A general, easily read booklet on Antara surfactants by the General Dyestuff Corp. Chart gives surfactants, the name, and the uses of these materials as well as a general chemical identification.

38 • CHEMIGUM. From Goodyear Tire & Rubber Co. a technical booklet on Chemigum, a nitrile synthetic rubber. Gives the property of the chemigum rubbers, compounding, applications, adhesives. Appendix gives much detail on physical properties of the material including resistance charts, raw material cost data, raw material suppliers, etc.

39 • HYDROGEN PEROXIDE. Pennsylvania Salt Mfg. Co., with a new bulletin on hydrogen peroxide prepared for workers who need a ready reference of general nature. Résumé of history, packaging, and labeling, uses of material with indications as to the best concentrations and methods for bleach results.

40 • DUST MANUAL. Fourth edition of "Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases," published by Western Precipitation Corp. Book is divided into three parts—Determination of Velocity and Volume of Gases, Determination of Concentration and Nature of Suspensions, Tables and Illustrations. Outlines standard method of procedure for the study of gas streams contained in industrial flue systems, and of suspended matter carried by these gases. An engineering study of value to those faced with dust-control problems.

41 • FIBERGLAS INSULATIONS. A manual on the use of Fiberglas insulation for industrial processes. Covers insulating wools, panels, mesh blankets, etc. Shows methods of application to pipes, tanks, conduits, etc. Gives prices and other data necessary for the use in insulation.

42 • RIGHT-ANGLE DRIVE. For centrifugal pumps and other industrial uses, Johnson Gear & Mfg. Co.'s right angle solid shaft gear drive. Standard dimensions, gear drive selection tables, pulley tables and descriptions of the units are given in bulletin, plus information on the five models. Tables show various combinations for various revolutions per minute and horsepowers from the units.

43 • PUMPS. A full line of pumps for corrosive, noncorrosive liquids, solids carrying liquids and dry and semidry materials is described in a new condensed catalogue of Yeomans Brothers Co. Catalogued in the above manner it tells how to select pumps, gives features of the types such as vertical, centrifugals, horizontal centrifugals, pneumatic ejectors, etc.

44 • COOLING TOWERS. Industrial cooling with a cooling tower filled with chemical stoneware Berl saddles is a product of Aqua-Therm, Inc. Towers have 50 sq. ft. of surface area for each cubic foot of volume. Forced or induced draft models are available. Bulletin shows a typical industrial cooling problem and how it is worked.

45 • HIGH PRESSURE EQUIPMENT. For the production, utilization, and measurement of pressures from 5000 to 200,000 lbs./sq. in. Harwood Engineering Co., Inc., has issued a descriptive catalog of its laboratory and industrial equipment. Covers high pressure intensifiers, gives specifications of all their models plus illustrations, high pressure pumps, industrial installations, flow diagrams, laboratory equipment, fittings, valves, instrumentation, pressure cells, stress and strain tables, etc.

46 • THERMO-REGULATORS AND THERMOSTATS. H-B Instrument Co.'s catalog of mercury-actuated thermoregulators and thermostats. Accuracy from ±0.0005° F. to 0.10° F. Relays, selector switches, etc., are all described. Range extremities from −35° F. to 350° F.

47 • PLASTIC PIPE AND FITTINGS. Engineering data on tubing, pipe valves and fittings made of Saran and polyethylene plastics. Bulletin of the American Hard Rubber Co. gives table of resistances for both plastics, dimensions and specifications of fittings, tube, tube fittings, tees, couplings, etc. Illustrated. Section on rods and sheets. Details of fabrication such as heat welding, friction welding, and other construction kinks are given.

48 • ENGINEERING RESEARCH. J. B. Calva & Co.'s 16-page illustrated brochure devoted to services the company renders. Consultants; the brochure is devoted to new ideas, processes, etc. Explains how engineering consultants operate. Shows equipment.

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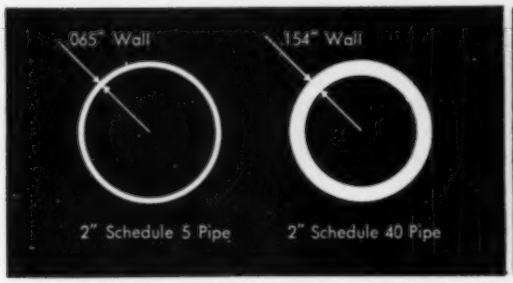

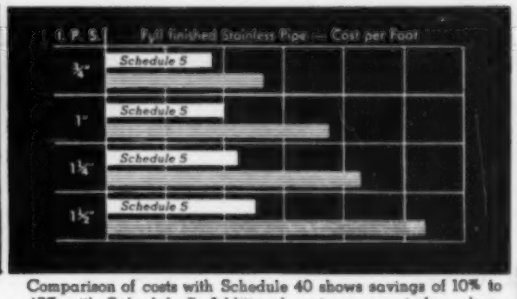

Comparison of costs with Schedule 40 shows savings of 10% to 45% with *Schedule 5*. Additional savings on costs for valves, fittings, etc. are also possible.

What Carpenter *Schedule 5* Pipe Is—

Its LIGHT WALL gives *more feet of pipe* for every pound of Stainless Steel. Cost is 40% to 50% lower. Larger I.D. increases flow area and permits use of a smaller pipe size.

You now have a way to help us improve the availability of Stainless Pipe for essential uses. And you can do it at a terrific saving in your costs.

You can hook up *Schedule 5* Pipe with existing lines of tubing or heavier wall pipe, Schedules 10 and 40.

For most jobs Carpenter *Schedule 5* Stainless Pipe handles the working pressures with a good margin of safety. Any working pressure up to 150 psi is handled by this pipe. In pipe sizes under 1½", higher pressures are frequently used.

More Stainless Pipe for essential uses is possible, even under today's conditions. To get the full story, call your nearest Carpenter Stainless Tubing Distributor. Or, write for a copy of the new "*Schedule 5* Data Sheets". We will be glad to send you a set.

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STAINLESS TUBING & PIPE

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SECRETARY'S REPORT

S. L. TYLER

THE Executive Committee met at the Office of the Institute on July 11. The Minutes of the previous meeting, the Treasurer's Report, and bills for the month of June, 1951, were approved. All those whose names appeared in the June issue of Chemical Engineering Progress as applicants for membership were elected to the grade of membership indicated.

D. D. MacLaren was appointed a vice-chairman of the Membership Committee. H. C. McCurdy was appointed to replace F. N. Browder representing the Knoxville-Oak Ridge Section and E. F. Thode was also added to the membership of this Committee.

Joseph D. Walk of the El Dorado Section and K. R. Jakto of the Charleston Section were appointed to the Public Relations Committee.

J. E. Maudru was appointed to replace C. H. Criswell on the Evaporators Subcommittee of the Testing Techniques and Equipment Performance Standards Committee.

Four resignations from membership were accepted and eight elections to membership were rescinded because of nonacceptance. DeWitt R. Gayle, Jr., Richard M. McFarland, and James F. Overton, Jr., were placed on the Suspense List as they have recently entered the Armed Forces.

L. H. Bartlett was appointed Counselor at the Student Chapter at Oklahoma A & M College to replace R. N. Maddox.

Several other matters were informally discussed, but final action was not taken.

Institute Directors 1952-1954 Nominees Suggested by Local Sections

FOLLOWING the practice established last year, the Secretary communicated with the local sections urging them to discuss at their meetings the possibility of suggesting a nominee for Director of the Institute for a three-year period starting Jan. 1, 1952. The response to this request was a good one, the results of which are given here. Where no local section is given, it may be understood that no suggestion was made by the section.

Section	*Nominee*
Akron	Ray P. Dinsmore
Charleston	Arthur K. Doolittle
Chicago	J. H. Rushton
Columbia Valley	R. S. Tour
East Tennessee	R. M. Boarts
Kansas City	C. W. Nofsinger
Knoxville-Oak Ridge	R. M. Boarts
Maryland	George Miller Hebbard
National Capital	Philip H. Groggins
New Jersey	J. C. Elgin
New Orleans	Edward A. Gastrock
Oklahoma	G. G. Oberfell
Philadelphia-Wilmington	Richard B. Chillas
Pittsburgh	Carl C. Monrad
Rocky Mountain	B. E. Lauer
South Texas	Ralph H. Price
Tennessee Valley	R. M. Boarts
Tulsa	Manson Benedict
Twin City	Ralph E. Montonna
Western Massachusetts	A. W. Low

The following sections advised us that they would not make a suggestion this year:

Boston	Northern California
Central Virginia	Rochester
El Dorado	St. Louis
New York	Washington-Oregon

The nominating ballot for officers and directors will be mailed from the Secretary's Office during the last week of August.

A.I.Ch.E. BULLETINS WANTED

Preparations are being made for a history of the first 50 years of the Institute. Valuable material for this purpose is to be found in the Bulletins of the Institute which reported fully the early meetings of the Institute, and the discussions on Institute policy. Unfortunately these Bulletins are very scarce. Even the Secretary's office does not have a complete file.

We would enjoy hearing from any of our members who have copies, complete or otherwise, of the early Bulletins of the Institute and who would be willing to donate them to us. As the clearing house for this, please write the Editor of Chemical Engineering Progress, 120 East 41st Street, New York 17, N. Y.

WHO'S RESPONSIBLE?

Chemical engineers interested in historical aspects of their profession can help W. L. Badger, internationally known authority on evaporation and consulting chemical engineer, the editor of *Chemical Engineering Progress*, and A. B. Stiles of the Du Pont Co., Inc., and former chairman of the Charleston Section, in clearing up a recurring point in chemical engineering technology.

The question being discussed by all three at present is: just who is responsible for the first multiple-effect evaporator? At the recent White Sulphur Springs meeting in his welcome to the members attending the meeting, Mr. Stiles said the first multiple-effect evaporator was "an associated sponsored development and the principle of the multiple effect evaporator found application in the Kanawha Valley in 1833 at least eight years before its known application anywhere else in the world." (Reported on page 24 of the April issue of *Chemical Engineering Progress.*)

In a recent film strip on evaporators prepared by Walter Badger for the A.I.Ch.E., credit was given, as is usually the case, to Norbert Rillieux, who constructed a unit for the evaporation of cane juice in Louisiana in 1843.

We called Badger's attention to the statement of Stiles and far from being a new fact to him he had recognized the possibility as early as 1927.

Walter Badger says that in Volume 1, dated 1836, *Journal of the American Institute*, which has long since been discontinued, there is on page 170 a "Letter to the Editor" on the subject of salt manufacture, in which the working of a multiple-effect evaporator is definitely described and ascribed to the Kanawha Salt Springs in Virginia.

The source of Mr. Stiles' information was an article by E. T. Crawford, Jr., *Industrial & Engineering Chemistry*, Vol *27*, 1935, which also ascribed the development to the Kanawha Valley salt operators.

If any of our readers can find or know of corroborating information, we certainly would be pleased to receive it.

CANDIDATES FOR MEMBERSHIP (*Continued from page 30*)

Robert C. Sparks, ***Tulsa, Okla.***
E. L. Stanisauskis, ***Ithaca, N. Y.***
Joseph Stewart, ***Cranford, N. J.***
David A. Strang, ***Girard, Ohio***
Donato R. Telesca, ***New Brunswick, N. J.***
Hugh W. Temple, Jr., ***Houston, Tex.***
Edwards Thompson, Jr., ***Omaha, Neb.***
George A. Trigaux, ***Dunbar, W. Va.***
Cecil E. Turnquist, ***St. Louis, Mo.***
Harrison Ruffin Tyler, ***Holdcroft P. O., Va.***
Joseph L. Verstraete, ***Detroit, Mich.***
Jack A. Wagner, ***Borger, Tex.***
Howard Wall, Jr., ***Norwood, Ohio***
William B. Ward, ***Elisabeth, N. J.***
Donald T. Watters, ***Louisville, Ky.***
Marlen G. Whippen, ***Glen Ridge, N. J.***
William R. Wild, ***Texas City, Tex.***
Boyd H. Wilkes, ***Joplin, Mo.***
Lester H. Wittenberg, ***Easton, Pa.***
Donald C. Wobser, ***Rochester, N. Y.***

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This HASTELLOY Alloy Condenser is still on the job in 1-10% Acid Solution

This condenser, made of HASTELLOY alloy B, shows no signs of corrosion after two and one-half years in a vacuum still for the distillation of hydrochloric acid. Since it was installed, the unit has been in operation two to three days a week, eight hours a day, handling a dilute solution of the corrosive acid at temperatures up to the boiling point.

HASTELLOY alloy B is one of the few commercially available materials that can handle boiling hydrochloric acid—one of the most severely corrosive agents known to the chemical industry. Alloy B is available in all standard wrought forms and can be fabricated by most common methods. Two additional HASTELLOY alloys, designated as C and D, are also available for handling other highly corrosive chemicals, such as sulphuric acid and certain strong oxidizing agents, like ferric chloride and wet chlorine.

The 28 in. tubes in this condenser for the distillation of hydrochloric acid are made from ½-in. diameter, 16-gage welded tubing of HASTELLOY alloy B. The end disks, which are ⅜ in. thick by 7 in. in diameter, are also of the nickel-base alloy.

For complete information, write for the 40-page booklet, "HASTELLOY High-Strength, Nickel-Base, Corrosion-Resistant Alloys." It contains data on the properties, available forms, and fabricating techniques for all three grades of HASTELLOY alloy.

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FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

Rochester, N. Y., Sheraton Hotel, Sept. 16-19. 1951.

Technical Program Chairman: D. E. Pierce, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.

Annual — Atlantic City, N. J., Chalfonte-Haddon Hall Hotel, Dec. 2-5, 1951.

Technical Program Chairman: Frank J. Smith, Pan American Petroleum & Transport Co., 122 East 42nd St., New York 17, N. Y.

Atlanta, Ga., Atlanta Biltmore Hotel, Mar. 16-19, 1952.

Technical Program Chairman: H. E. O'Connell, Ethyl Corp., Box 341, Baton Rouge, La.

French Lick, Ind., French Lick Springs Hotel, May 11-14, 1952.

Technical Program Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

Chicago, Ill., Palmer House, Sept. 4-6, 1952.

Technical Program Chairman: D. A. Dahlstrom, Chem. Eng. Dept., Northwestern University, Evanston, Ill.

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.

Technical Program Chairman: R. L. Savage, Dept. Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

Toronto, Canada, Royal-York, April 27-May 2, 1953.

Annual—St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.

SYMPOSIA

Maintenance

Chairman: D. E. Pierce, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.
Meeting—Rochester, N. Y.

Industrial Applications of Photography

Chairman: Carl Gath, Eastman Kodak Co., Kodak Park Works, Rochester, N. Y.
Meeting—Rochester, N. Y.

Round Table Discussion of Chemical Engineering Education

Chairman: W. E. Gift, Tennessee Eastman Corp., Kingsport, Tenn.
Meeting—Rochester, N. Y.

Opportunities in Sales for Chemical Engineers

Chairman: F. J. Curtis, Monsanto Chem. Co., 75 Rust Bldg., 1001 15th St. N.W., Washington 5, D.C.
Meeting—Atlantic City, N. J.

Chemical Engineering Fundamentals

Chairman: W. C. Edmister, Chem. Eng. Dept., Carnegie Inst. of Tech., Pittsburgh 13, Pa.
Meeting—Atlantic City, N. J.

Effective Speaking

Chairman: L. P. Scoville, Jefferson Chem. Co., 711 Fifth Ave., New York 22, N. Y.
Meeting—Atlantic City, N. J.

Vacuum Engineering

Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.
Meeting—French Lick, Ind.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

SUMMER SERIES AT OAK RIDGE ANNOUNCED

"Engineering in Nuclear Energy Development" is the theme of the third annual summer symposium sponsored by the Oak Ridge National Laboratory and the Oak Ridge Institute of Nuclear Studies. Sessions of the 1951 symposium scheduled to be held at Oak Ridge from Aug. 27 to Sept. 7 will be unclassified in nature and will be open to all interested professional engineers.

Symposium subjects and speakers include:

The Contributions of Engineering to Nuclear Energy Development—J. A. Lane, head, long-range reactor planning group, ORNL.
Elementary Nuclear Concepts—A. M. Weinberg, research director, ORNL.
Simplified Approach to Reactor Calculations—Speaker to be announced.
Economic Aspects of Atomic Power—Sam H. Schurr, chief economist, Bureau of Mines, U. S. Department of the Interior.
Stable Isotope Separations—Manson Benedict, professor of chemical engineering, Massachusetts Institute of Technology, chief of operations analysis, A.E.C.
Standards of Radiological Protection and Control—Karl Z. Morgan, director, health physics division, ORNL.
Environmental Problems of Radioactive Waste Materials—R. J. Morton, health physics division, ORNL.
The Treatment of Radioactive Wastes,—Warren K. Eister, chemical technology division, ORNL.
Thermal Problems in Reactor Design—R. N. Lyon, reactor technology division, ORNL.
Instrumentation and Control of Reactors—J. D. Trimmer, associate professor of physics, University of Tennessee.
The Chemical Problems in the Development of Reactors—J. A. Swartout, acting director, homogeneous reactor project, ORNL.
Review of Reactor Types—Neal F. Lansing, reactor technology division, ORNL.
Hazards Associated with Low Power Research Reactors—M. M. Mills, North American Aviation Corp.
The Materials of Reactor Construction—G. E. Evans, physics division, ORNL.
The Scope of Nuclear Engineering Education—A. M. Weinberg.
The Nuclear Engineering Curriculum at North Carolina State College—C. K. Beck, chairman, department of physics, North Carolina State College.
The Impact of Atomic Energy Developments on the Training of Professional Engineers—L. M. K. Boulter, dean, college of engineering, University of California at Los Angeles.
The Oak Ridge School of Reactor Technology—F. C. VonderLage, director, educational relations and training division, ORNL.

The last four subjects will form a panel discussion on the last day of the symposium; R. C. Ernest, dean of the Speed Scientific School of the University of Louisville, will be chairman.

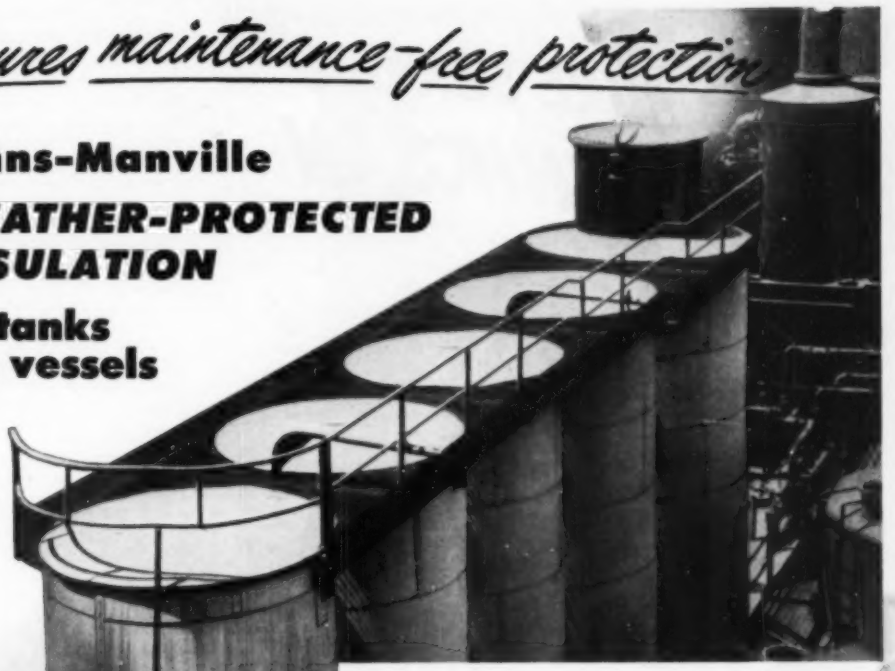
For details write University Relations Division, Oak Ridge Institute of Nuclear Studies, P. O. Box 117, Oak Ridge, Tenn.

Assures maintenance-free protection

Johns-Manville

WEATHER-PROTECTED INSULATION

for tanks and vessels

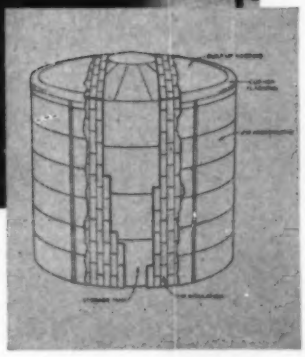


If you have outdoor—or indoor—tanks and vessels . . . such as the multiple effect evaporators shown above . . . it will pay you to look into Johns-Manville Weather-Protected Insulation.

Weather-Protected Insulation pays because it does a twofold job: 1. It provides the close temperature control so important in the process industries; 2. It assures a maintenance-free insulation job.

Basically, this Johns-Manville Weather-Protected Insulation specification consists of standard J-M Insulations over which is applied Johns-Manville Asbestocite (a tough, strong asbestos-cement sheet) to protect the insulation from the weather or from wetting due to normal plant operations. Shielded in this manner, the insulation maintains its original efficiency and requires no periodic maintenance.

If you wish, a Johns-Manville Insulation Engineer will be glad to survey your equipment and make appropriate recommendations. For further details, send for a copy of folder IN-121A. Address Johns-Manville, Box 290, New York 16, N. Y.



Cutaway drawing shows how Johns-Manville Weather-Protected Insulation is applied to a tank—Standard methods for mechanical securement of the insulation are used. Asbestocite sheets are then applied over the insulation, following a simplified Johns-Manville specification.

JOHNS-MANVILLE JM PRODUCTS

Johns-Manville *first in* INSULATIONS

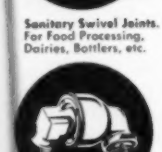
for SAFE, SURE SERVICE SPECIFY CHIKSAN

Standard Swivel Joints. For pressures from 125 psi. to 15,000 psi.

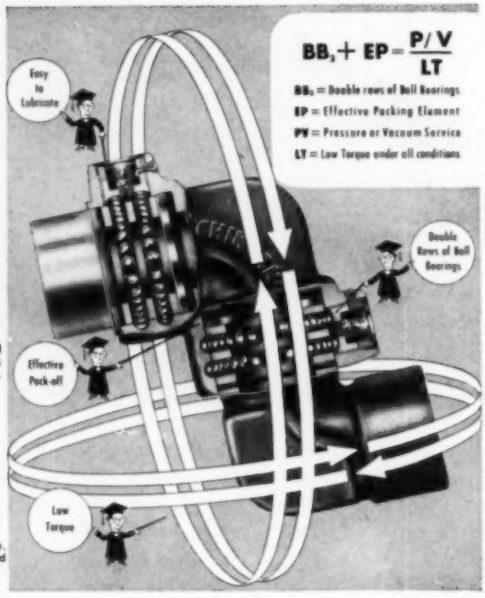
High Temperature Swivel Joints. For temperatures to 500°F. M.W.P. 700 psi.

Rotating Joints. For 150-lb. steam, brine, etc. Adapted for siphon return line.

Sanitary Swivel Joints. For Food Processing, Dairies, Bottlers, etc.



Hydraulic Swivel Joints. For pressures to 3,000 psi.


$BB_2 + EP = \frac{P/V}{LT}$
BB_2 = Double rows of Ball Bearings
EP = Effective Packing Element
PV = Pressure or Vacuum Service
LT = Low Torque under all conditions
Easy to Lubricate
Double Rows of Ball Bearings
Effective Pack-off
Low Torque

For over a quarter-century, here at CHIKSAN, we have specialized *exclusively* on developing and designing Swivel Joints* for all purposes... on manufacturing them to our rigid standards of precision... and on following through in the field to check performance under all sorts of conditions. That's why there is no substitute for CHIKSAN *Ball-Bearing* Swivel Joints* when it comes to efficient service with maximum safety... longest life... and minimum maintenance.

It costs you nothing to take full advantage of CHIKSAN's *specialized* experience. CHIKSAN Engineers will gladly cooperate with you in designing flexible lines to meet your specific requirements.

WRITE FOR CATALOG NO. 50-C. REPRESENTATIVES IN PRINCIPAL CITIES—SOLD BY LEADING SUPPLY STORES EVERYWHERE

*For full 360° rotation in 1, 2 and 3 planes. Unlimited flexibility in pipe lines is secured merely by arranging swivels in proper sequence. Over 500 different Types, Styles and Sizes for pressures to 15,000 psi; temperatures to 500°F.; pipe sizes from ⅜" to 12" and larger.

CHIKSAN TRADE MARK

CHIKSAN COMPANY
AND SUBSIDIARY COMPANIES
Chicago 3, Ill. BREA, CALIFORNIA Newark 2, N. J.
WELL EQUIPMENT MFG. CORP. HOUSTON 1, TEXAS
CHIKSAN EXPORT CO. BREA, CALIFORNIA NEWARK 2, N. J.

BALL-BEARING SWIVEL JOINTS FOR ALL PURPOSES

ISOOCTYL PLANT FOR S. O. (IND.)

Plans for construction of a complete plant to produce isooctyl alcohol at the Wood River (Ill.) refinery of Standard Oil Company (Ind.) were announced recently by M. G. Paulus, vice-president in charge of manufacturing. The plant is being designed for the production of 10,000,000 lbs. of isooctyl alcohol/year.

One principal use of this chemical is in the manufacture of additives for the production of heavy duty motor oils. Final design of the isooctyl alcohol plant is now being completed and based on projected schedules, the installation will be completed before the end of 1952.

Isooctyl alcohol is also used in large quantities for the manufacture of plasticizers for vinyl resins.

HYDRAULICS CONFAB FOR CHICAGO

The seventh annual National Conference on Industrial Hydraulics will be held Nov. 8 and 9 in the Sherman Hotel in Chicago, according to the conference director, John J. Slomer, Goodman Manufacturing Co., Chicago. The two-day meeting is devoted to presentation of topical, technical papers by authoritative speakers on the latest developments in the industrial hydraulics field.

Sponsors of the nonprofit, noncommercial meetings are the Graduate School of Illinois Institute of Technology and Armour Research Foundation of Illinois Institute of Technology. Cooperating societies are the local sections and chapters of national engineering societies including the Chicago Section of the American Institute of Chemical Engineers.

ENERGY SOURCES

(*Continued from page* 21)

we should hoard our fossil fuels wherever possible, particularly petroleum.

2. There are distinct possibilities of greater development and use of continuous sources of energy probable within 100 years.

3. Energy sources, limitations, and locations may well influence our living patterns through change in architectural design, industrial locations, comparative price of fuels, and the development of more integrated energy systems.

4. We should be willing to pay a premium now in terms of research and development to effect conservation of our least adequate in amount, but most useful in form sources of energy. Such research as shale oil recovery, liquid fuels from coal, utilization of vegetable wastes, etc., should continue to receive adequate public support.

5. We should direct conservation effort preferentially to areas of largest consumption such as space heating and provision of process heat.

6. In the public interest, we should eliminate wasteful processes where conservation could be effected by substitution even if such substitution results in a temporary economic disadvantage.

MANPOWER

(*Continued from page 21*)

persons, of whom an estimated 25% are equipped to do research." The 25% figure represents roughly 130,000 research people, he said, of whom about 25,000 are employed full time by government, 70,000 by industry, and 35,000 by colleges and universities. "The total number of engineers and scientists," he continued, "now required for the Department of Defense research program of $1.1 billion, rounds out the 56,000 or 43% of the total national supply. It is expected that in 1952 this percentage will rise to 52%, with a total requirement for 68,000 technically trained personnel. If the Atomic Energy Commission and other agencies engaged in defense research are included, the requirements reach a staggering 65%."

Another session at the conference was given over to public relations in engineering research, during which Allen Will Harris, public relations consultant, told the educators that scientific organizations and technical groups "present some of the most difficult problems in the public relations field . . . ."

Mr. Harris defined public relations as "anything you do that affects what another man thinks of you" and listed four special problems in this field now confronting engineering research as:

1. Security regulations which prohibit normal communication between the employee and his neighbor, the organization and its community, the scientist and his colleague, and between science and the lay public.
2. The time-scale of major research is dangerously misunderstood; results cannot come overnight. The gap between what competent technical men can do and what self-promoters claim can be done is every day widening.
3. An increasing amount of research is dedicated to the development of materials and weapons of destruction. Scientists may find, when world emphasis changes, that they have become "merchants of death."
4. No species is more difficult to organize and manage than the modern technical man and scientist, because he may fail to realize that human problems cannot be solved without regard for human nature.

PHOSPHATE CO. TO INT. MINERALS & CHEM.

International Minerals & Chemical Corp. has purchased the Thomson Phosphate Co., according to an announcement by Franklin Farley, vice-president in charge of International's phosphate division.

Thomson Phosphate Co., which was organized in 1920 with headquarters in Chicago, has maintained a sales and distributing organization for the distribution of fine-ground phosphate rock to dealers and farmers for direct application to the soil. The company ships regularly to approximately 500 dealers in 28 states, and International Minerals & Chemical Corp. is its source of raw material.

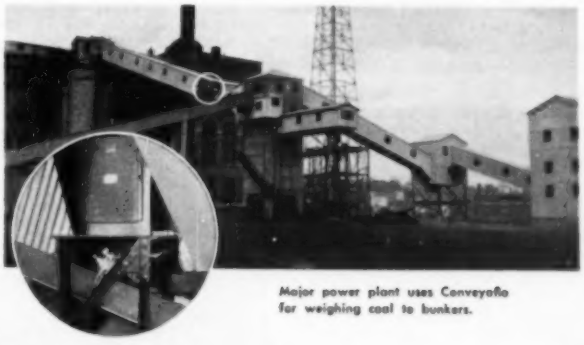
MATERIALS WEIGHED AS FAST AS CONVEYED

BUILDERS *Conveyoflo*

"THE FLOW METER FOR DRY MATERIALS"

By installing Builders Conveyoflo Meters, you can now obtain a complete record of the weight of dry materials flowing over your conveyor lines — accurate within ± ½ of 1% of actual weight from 100% to 50% of maximum rate; ± 1% from 50% to 25% maximum rate; ± 2% from 25% to 10% maximum rate. This is mighty important to the modern processing plant. No longer is it necessary to interrupt the flow of materials, or resort to batching or other intermittent processing techniques. Conveyoflo, with its pneumatic metering system, packs a lot of dependability into very little space. It is almost completely contained within the original dimensions of the conveyor line itself. For complete information and new Bulletin 550-H4, address Builders-Providence, Inc. (Division of Builders Iron Foundry), 419 Harris Avenue, Providence 1, Rhode Island.

BUILDERS makes a complete line of flow meters and controllers for liquids, steam, air, gas, and dry materials . . . mechanical and differential . . . including The Venturi Meter and Chlorinizers (chlorine gas feeders).



Major power plant uses Conveyoflo for weighing coal to bunkers.

BIF INDUSTRIES — BUILDERS PROVIDENCE *Instruments* — BUILDERS

A REGULAR SERVICE OF THE **COOPER ALLOY** FOUNDRY CO., HILLSIDE, N. J.

Technical Topics

MACHINING 18-8 STAINLESS STEEL--- METALLURGICAL CONSIDERATIONS

Norman S. Mott
Chief Chemist and Metallurgist

Most of the headaches associated with the machining of stainless alloys can be cured with machining experience, but some of them are associated with metallurgical considerations. This applies both to the wrought and the cast materials. Too often the underlying causes and the possibilities for their correction are not well understood. The purpose of this discussion is to review these causes, and to indicate the steps which may be taken to eliminate them.

The basic difficulties experienced in the machining of stainless alloys are:

1. The metal is too hard. . . . The cutting tool cannot penetrate or too much cutting tool pressure is required.
2. The metal is too tough. . . . It tears away instead of breaking up into chips.
3. Frictional or galling characteristics are excessive. . . . Chips adhere to the tip on the tool, resulting in the balling up of the cut metal.
4. Microstructural non-uniformity or segregation. . . . This causes hard spots and results in rough or uneven machined surfaces.
5. The metal work hardens. . . . This results in a blunt tool and a polishing rather than a cutting action. Let us review each of these difficulties in turn:

Hardness: Hardness in 18-8 stainless, such as to cause difficult machining is not an inherent characteristic. It is usually found in the form of work hardening, either from cold rolling or from hot working to too low a temperature. Although machining operations have been conducted up to as high as 350 Brinell, this requires a slow special technique and for practical purposes such hard metal should be soft annealed by water quenching from 1950-2100° F.

Toughness: Correctly heat treated 18-8 stainless in the condition for maximum corrosion resistance is very tough and ductile. These are desirable characteristics from a mechanical viewpoint, but they are pretty tough on machinability. Experience has shown that machining difficulties can be minimized through the addition of an embrittling agent such as selenium, sulphur or phosphorus. And when properly controlled, maximum machinability with a minimum loss of corrosion resistance can be accomplished.

Galling: Galling tendencies, which are associated with softness and ductility, are also largely eliminated by controlled additions of various alloying elements.

Hard Spots: Hard spots are caused by microstructural segregations such as carbides and other hard phases. The machining tool in passing over these areas does not cut properly and gives a raised and usually a glazed surface, producing a so-called "orange peel" effect. Correct quench annealing heat treatment is required in order to eliminate such a condition. Another cause of hard spots may be burnt-in pieces of molding sand, a condition sometimes found in poor quality castings.

Work Hardening: Work hardening is a universal characteristic of the 18-8 stainless steels. Pressure by the machine tool tends to cold work the surface and make it hard. To offset this, there are a number of machinists' tricks which are somewhat beyond the scope of this discussion. (Further data on the machining techniques can be found in J. J. Roberts' paper, "Don't Fear Threading of Stainless.")

Available on Request

Copies of this article, printed on heavy stock in convenient filing form are available. In addition, reprints of Mr. Roberts' more complete paper will gladly be sent to you, without obligation, in small quantities. Address your requests to Publicity Dept., The Cooper Alloy Foundry Co., Hillside 5, N. J.

COOPER ALLOY
Stainless Steel
VALVES · FITTINGS · CASTINGS

DIAMOND JUBILEE FOR A.C.S.

New York City will be host to members of the American Chemical Society the week of September 3, for the organization's Diamond Jubilee meeting. The A.C.S. was founded in New York in 1876, and during the meeting a plaque will be unveiled at Washington Square by C. L. Parsons, Secretary of A.C.S. from 1907-1945, commemorating that event. The A.C.S. Jubilee will be followed by the Sixteenth Conference of the International Union of Pure and Applied Chemistry and the Twelfth International Congress of Pure and Applied Chemistry, the host for these events being the National Research Council.

President Truman has been invited to speak at the A.C.S. Diamond Jubilee banquet according to an announcement by N. Howell Furman of Princeton University, president of the Society, and Dr. C. E. K. Mees of the Eastman Kodak Co. will speak on "The View Ahead in Chemistry."

Gov. Alfred E. Driscoll of New Jersey will be the principal speaker at a general meeting of the Society in Manhattan Center on Monday evening, Sept. 3.

The week of the Society's Jubilee meeting has been designated as National Chemistry Week, and a special anniversary stamp has been approved by the Post Office Department.

Dr. James Bryant Conant, president of Harvard University and honorary president of the International Congress of Pure and Applied Chemistry, will be the main speaker at a ceremonial in the 71st Regiment Armory, Park Avenue and 34th Street, at which representatives of foreign and domestic scientific societies, in full academic regalia, will present scrolls of greeting to the American Chemical Society.

At the Society's general meeting in addition to Governor Driscoll's address, there will be a presidential address by Professor Furman, who is chairman of the Princeton chemistry department, and a Priestley Medal address by E. J. Crane of Columbus, Ohio, editor since 1914 of the Society's semimonthly publication "Chemical Abstracts."

Technical sessions of the meeting will begin Tuesday morning, Sept. 4, and more than 700 papers will be presented at a total of 80 symposia.

The International Union of Pure and Applied Chemistry, a continuing organization with headquarters in Paris, which has 32 member countries represented by government agencies or outstanding chemical societies, will hold the New York sessions of its Sixteenth Conference on Saturday and Sunday, Sept. 8-9. The Union meets every two years

(*Continued on page 47*)

ASBESTOS CANNOT CARBONIZE—IT ENDURES FOREVER

AVOID THIS! ➡

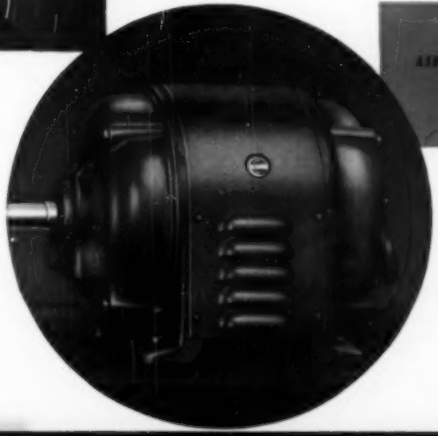
U. S. MOTORS

are asbestos-protected

Life of a motor is proportional to the life of the insulation protecting its windings. While there is no way to guarantee perpetual life, there *is* a method of insulating the windings so that life will be infinitely increased—by using *asbestos insulation*. That is the proved element used in insulating the windings in U. S. Motors. Asbestos is the greatest of all pliable, heat-resisting materials.

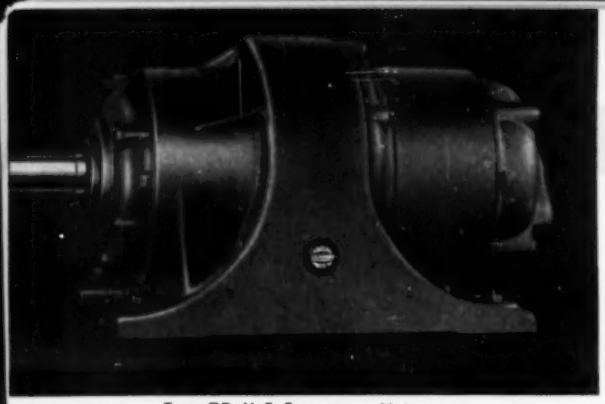
U. S. WINDINGS MOST RESISTANT TO HEAT

A burnt-out motor is evidence that the windings have failed. Commonly used cellulose materials can carbonize, changing from insulator to conductor, whereas asbestos is a fibrous rock whose silken fibres can turn red hot but *cannot carbonize*. U. S. windings are forever protected.

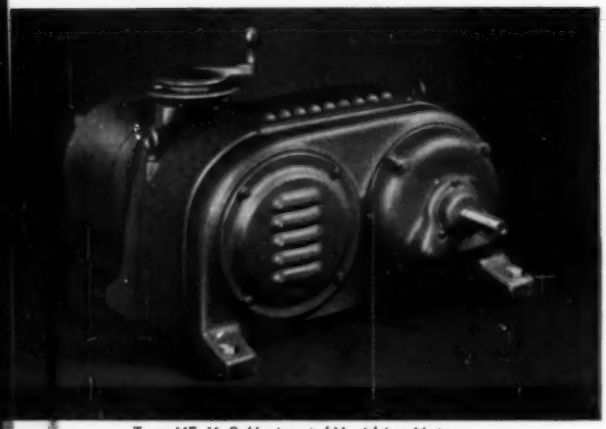


(A)—Empty stator slot before insulating and winding. (B)—Formed cell of asbestos providing a heat-proof wall of insulation. (C)—Cross section showing wires inserted, with asbestos cell covering entire winding. Asbestos plateboard in center of slot separating and insulating between coils. (D)—Asbestosite (in color) forced around windings, penetrates every interstice.

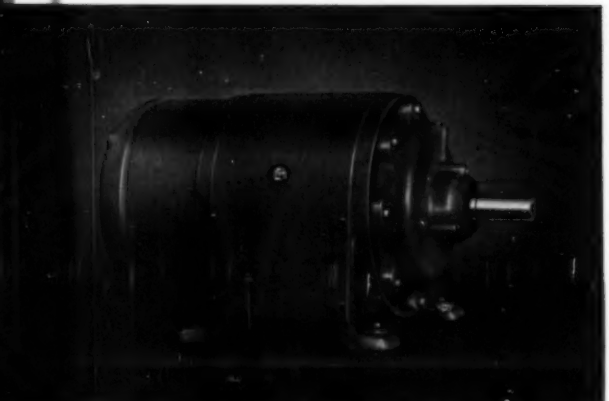
(See next page)



Type GD, U. S. Syncrogear Motor



Type VE, U. S. Horizontal Varidrive Motor



Type SE or SD, U. S. Totally-Enclosed Fan-cooled Motor

U. S. MOTORS

offer these advanced features:

ASBESTOS-PROTECTED WINDINGS
NORMALIZED CASTINGS
ANNEALED STEEL LAMINATIONS
SOLID CENTRICAST ROTORS
DUAL CYCLONE VENTILATION
LUBRIFLUSH LUBRICATION
STREAMLINED, SHIELDED HOUSINGS

Since the inception of U. S. Motors in 1908, a highly successful principle has been maintained—*to build up to a quality*, not down to a price. You can sense U. S. quality in the appearance of these motors. But even more impressive are the many advanced features that insure longest life.

Every U. S. Motor is asbestos-protected—because asbestos *cannot* carbonize. This is an exclusive U. S. feature. By normalizing castings, bearing alignment is maintained so that destructive stresses cannot occur. Lubriflush lubrication presents a convenient means of purging the bearings of old, worn-out grease and replacing the entire bearing chamber with new lubricant without disturbing the bearing setting. The bearings are also self-lubricated for normal life so that even if the old grease is never replaced, bearings are protected.

YOU'LL FIND LOTS OF INTEREST IN THIS BULLETIN
—showing 15 latest types of U. S. Motors

All types of U. S. Motors reproduced from natural color photos are included, to give you a clear conception of the extensive line available. Write for Bulletin 1543. Mention type of motor you desire and Bulletin featuring that type of motor will also be sent.

U.S. ELECTRICAL MOTORS Inc.

PACIFIC PLANT: Los Angeles 54, California **ATLANTIC PLANT: Milford, Connecticut**

Atlanta 3, Ga.; Bakersfield, Calif.; Boston 16, Mass.; Chicago 8, Ill.; Cincinnati 16, Ohio; Cleveland 14, Ohio; Dallas 9, Texas; Detroit 2, Mich.; Fresno 1, Calif.; Houston 4, Texas; Indianapolis 4, Ind.; Milwaukee 2, Wisc.; Minneapolis 2, Minn.; New York City 6, N. Y.; Philadelphia 2, Pa.; Pittsburgh 2, Pa.; San Francisco 7, Calif.; Seattle 4, Wash. » » » » *Distributors and Agents in all principal cities.*

ATLANTIC REFINING PROCESS LICENSED

The Atlantic Refining Co. announced recently that it has a patent license agreement with the Richfield Oil Corp. covering the operation by Richfield of Atlantic's new catalytic reforming process utilizing a platinum-containing catalyst. (*Chem. Eng. Progress*, page 20, March, 1951.) Richfield's initial application will involve the conversion of about 6,000 bbl./day of closely fractionated feed stock to benzene and aviation gasoline aromatics concentrate.

The Sinclair Refining Co. has also acquired the right to proceed with installations to use the process, and is now examining the economics of such installations at capacity levels of 20,000 bbl./day of gasoline.

Atlantic has under construction a large plant at its Philadelphia refinery to utilize the process to produce high-quality gasoline.

V-BELT MANUAL AVAILABLE

The Rubber Manufacturers Association, Inc., and the Multiple V-Belt Drive & Mechanical Power Transmission Association have issued a 16-page manual on recommended "Engineering Standards for Multiple V-Belt Drives," as developed and approved by the technical committees of both associations. The manual is based on the latest engineering research and indicates the proper sheaves and belts to be used for optimum efficiency in relation to duty.

The standards may be obtained at a cost of $1.00 for two copies from either the Multiple V-Belt Drive Association, 7 West Madison Street, Chicago 2, Ill., or the Rubber Manufacturers Association, Inc., 444 Madison Ave., New York 22, N. Y.

A.C.S. JUBILEE

(*Continued from page* 44)

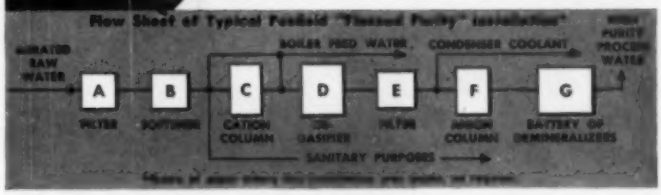
in a member country to set uniform chemical standards for the scientists of the world in such fields as atomic weights, nomenclature, toxicology and industrial hygiene, and radioactivity.

A total of 971 papers prepared by more than 2,500 authors will be presented at the Twelfth International Congress of Pure and Applied Chemistry, which starts Monday, Sept. 10.

The Congress, which is not a continuing body like the Union, meets every fourth year in the country in which the Union is convening that year. The last congress met in London in 1947. Host for the 1951 Congress, as for the Union Conference, is the National Research Council's division of chemistry and chemical technology.

✓ Process Improved
✓ Rejects Decreased
✓ Costs Lowered
✓ Production Increased

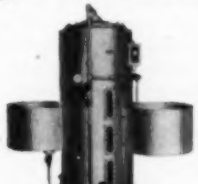
with "PLANNED PURITY" WATER



Problem Assigned Penfield: Raw well water of 347 PPM total hardness (calculated as $CaCO_3$) and 187 PPM alkalinity, methyl orange, as well as considerable hydrogen sulphides, needs to be conditioned for use as follows: 1300 gph for boiler feed water and sanitary purposes; 100 gph for use as make-up water for a condenser coolant; and 2500 gph for a process requiring exceptionally high purity water.

"Planned Purity" Solution: Aerated raw water is passed through Sand Filter (A) to remove colloidal sulphur (precipitated by aeration), then through Softener (B), at which point water of satisfactory softness for sanitary purposes is drawn off. Approximately 3000 gph of softened water passes on to large Cation Column (C) where the cations are removed and the 187 PPM of alkalinity are converted to carbonic acid which can be blown from the water into the Degasifier (D) as carbon dioxide. The degasified water then is pumped through the Sand Filter (E) and on to the Anion Column (F). However, provisions are made (1) for combining water taken from the large Cation Column with equal parts of water taken from the Softener to make an ideal blend for boiler feed use; and (2) for drawing off 100 gph of water demineralized down to approx. 20 PPM total solids, which with small additions of caustic soda is ideal for use as make-up water for a condenser coolant. The remaining water passing through this multiple-use conditioning system goes on to a battery of Demineralizing Units (G) which deliver approximately 2500 gph of the exceptionally high purity water (conductivity of 1,000,000 ohms) required in the plant's process.

NEW! **Mono-Bed Unit**



The Penfield Mono-Bed Demineralizer shown above operates upon the most efficient and effective deionizing technique known — the intimate mixing in a single container of cation and exceptionally strong anion base exchangers. In comparison to distilled water costs, Penfield Industrial Demineralizers provide savings as high as 85%, and in one reported instance cut costs 98%. Send for "Penfield Pays" folio giving specifications of all Penfield Demineralizing Units — from 10 gals/hr. to 10,000 gals/hr.

LET PENFIELD ENGINEERS MAKE A "PLANNED PURITY" SURVEY OF YOUR PLANT

As in the typical "Planned Purity" installation described above, by *planning* water-treating methods specifically for the various standards of purity and quantities required, Penfield engineers often are able to suggest a *multiple-use* conditioning system which, while holding equipment investments to a minimum, makes important contributions *both* to reduced plant operating costs *and* to improved process or end product results.

Write today describing your water conditioning needs.

PENFIELD

MANUFACTURING CO., INC.

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FILTERS · SOFTENERS · DEGASIFIERS · DEMINERALIZERS

Penfield "Planned Purity" PAYS!

Lapp

AUTO-PNEUMATIC

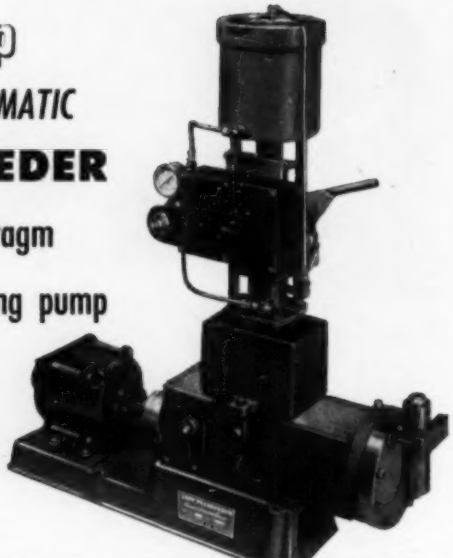
PULSAFEEDER

piston-diaphragm

chemical metering pump

with automatic

output control



For automatic metered pumping of corrosive or "hard-to-handle" chemicals, the Lapp Auto-Pneumatic Pulsafeeder offers new accuracy, efficiency and dependability. Applicable to all pneumatic or electro-pneumatic instrumentation, the Auto-Pneumatic Pulsafeeder provides automatic metering in response to variable flow, pH, temperature, liquid level, pressure, or other processing variables. The Pulsafeeder accomplishes this with a pump that operates at a constant pumping speed; variable flow results from variation only in piston stroke length, controlled by the pneumatic cylinder. In addition, through a manual ratio control, means is provided for accurate adjustment of output rate independent of instrument air pressure changes. And the Lapp Pulsafeeder is the positive displacement proportioning pump that operates without stuffing box or running seal. Its hydraulically-balanced diaphragm acts as a floating partition which isolates the chemical being pumped from pump parts—to protect against contamination of product or equipment. Entire mechanism inherently explosion-proof.

WRITE for complete description and specifications. Lapp Insulator Co., Inc., Process Equipment Division, 451 Maple St., LeRoy, N. Y.

Lapp

PROCESS EQUIPMENT

CHEMICAL PORCELAIN VALVES • PIPE • RASCHIG RINGS

PULSAFEEDER CHEMICAL PROPORTIONING PUMPS

MARGINAL NOTES

(Continued from page 28)

Science and Your Happiness

The Impact of Science on Society. Bertrand Russell, Columbia University Press, New York, N. Y. (1951) 64 pp. $2.00.

Reviewed by F. J. Van Antwerpen, Editor of Chemical Engineering Progress.

THIS new book by Bertrand Russell consists of three lectures which the British philosopher gave at Columbia University, November, 1950; the chapters bearing the titles of the lectures are "Science and Tradition," "Effects of Scientific Technique," and "Science and Values."

The theme throughout this volume is that the future of the world will be decided within our lifetime, and (like almost everything else in life) it is either going to be better, or it is going to be worse. The book is easy to read. Russell being quite free of philosophic gobbledegok, and is stimulating to a great degree to the thought of the reader. Russell's position as a philosopher and Nobel Laureat is well known and his thoughts on the subject of science should receive attention from our profession.

The first chapter traces the effect of science on tradition, and the impact of science on the superstition of ancient and modern peoples is examined by the author, though not exhaustively, since that would be impossible in so short a space. Russell does use a great deal of wit and original observation. At one point he defines the concepts of the mechanistic outlook and defends its purposes. He has an enjoyable time for himself with the effect of Darwinism on theology—"when the absence of any sharp line between men and apes was very awkward for religion and posed the question—'Did the Piltdown man go to heaven?'"

The important point he makes in the chapter is that science had and is having a tremendous effect on tradition. He states that though Darwinism indicates that men are not all equal in congenital endowment, this does not carry through into political arguments as some totalitarians would advocate.

As an example of the type of ideas with which he confronts the reader, in the second chapter on "Effects of Scientific Technique," he says: "War has been throughout history, the chief source of social cohesion; and since science began, it has been the strongest incentive to technical progress."

A few pages later he comes up with the even more chilling though thought-provoking idea, when speaking of biology and its effect on animals and the importance of selective breeding—"When such methods of modifying the congenital character of animals and plants have been pursued long enough to make their success obvious, it is probable that there will be a powerful movement for applying similar methods to human propagation. There would at first be very strong religious and emotional obstacles to the adoption of such a policy. But suppose say, Russia were able to overcome these obstacles and breed a race stronger, more intelligent, and more resistant to disease than any race of men that has hitherto existed, and suppose other nations perceived that unless they followed suit they would be defeated in war; then either the other nations would voluntarily forego their prejudices, or, after defeat, they would be compelled to forego them. Any scientific technique, however beastly, is bound to spread if it is useful in war—until such time as men decide that they have had enough of war and will henceforth live in peace."

However, Russell does point out that much of our present comfort and mastery over nature is due to our success with the scientific technique. The chapter closes with the thought that though science has enabled man to produce more and have a surplus of labor, we do not use it wisely, and we set a larger portion aside for war than our ancestors.

He then traces the large-scale disadvantages of our time from failure to extend the domain of law to the settlement of disputes.

The last chapter contains much that will be disputed and possibly be offensive to many religious persons. Here he claims there are two ancient evils that science unwisely used, can intensify, namely—tyranny and war. But he also lists many present advantages and improvements that science can confer. It can abolish poverty, excessive hours of labor, and raise the standard of life, through medicine, and make for healthier people and a general decrease in human suffering.

He finds that today, the average level of happiness in Britain as well as in America is higher than in any previous community at any time. He then goes on to stress the kind of nostalgic despair which is not now uncommon and proves it to be irrational. He calls for a greater effort of mankind to be optimistic, feeling that one more effort toward peace will be all that is needed. Science in his opinion, offers the possibility now of far greater well-being for the human race than it has ever known, but it offers this in his opinion, on certain conditions

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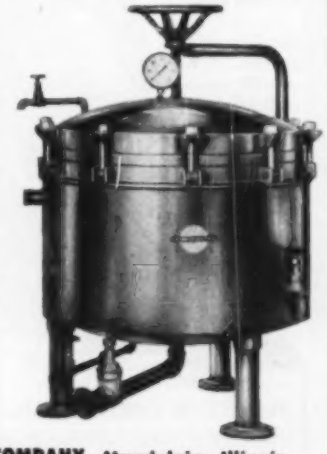

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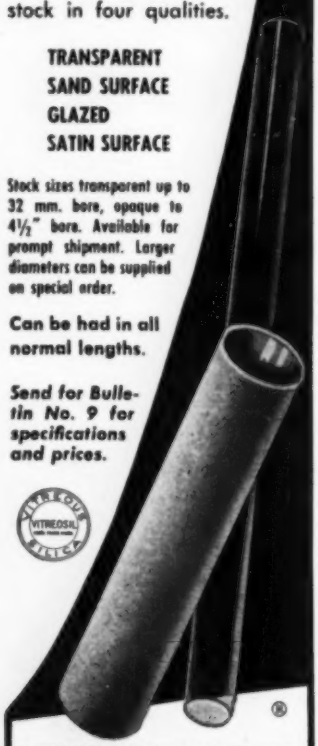

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As of now, he states there are only two sovereign states—Russia and the United States, and if either becomes preponderant leader either by victory in war or by an obvious military superiority, the preponderant power can establish a single authority over whole areas and thus make future wars impossible.

At present, Russell says, "The human race could, here and now, begin a rapid approach to a vastly better world, given one single condition: the removal of mutual distrust between East and West. I do not know what can be done to fulfill this condition. . . . Meanwhile, the only thing to do is to prevent an explosion. . . . The near future must be either much better or much worse than the past; which it is to be I do not know, but those of you who are still young will know before very long."

The book should be read by all scientists, humanitarians, and educators for the raw thought and the mental processes that are used by Russell in evaluating the impact of the great force of science on the nations of the world. Its effect on manners and morals, religions, social institutions and governments cannot be denied, and such studies as this, which traces its effects are indeed valuable to any educated and competent person in our field.

Solves Your Water Treatment Problems

Water Supply & Treatment. National Lime Association, Washington, D. C., Bulletin 211 (1951) 209 pp., $1.25.

FROM the National Lime Association comes a new seventh revised edition of the well-known book, "Water Supply & Treatment." The new edition contains a number of important revisions covering disposal and reclamation of lime sludge, versenate method of determining hardness, polystyrene base exchange, and methods of recarbonating softened water. The book is the work of the late Charles P. Hoover; it contains 16 chapters, and 99 illustrations. Technical titles of the chapters are—Source of Water Supply, Methods of Water Purification, Filters and Filtration, Disinfection or Sterilization, Water Softening, Chemistry of Lime-Soda-Ash Process, Zeolite Processes, and an extensive chapter on Skeleton Methods of Analysis.

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ADVISORY COMMITTEES NAMED BY N. P. A.

Memberships in various National Production Authority Committees for the chemical industry were announced last month. Four industries were covered as shown in the following listing.

Nitrogen

F. T. Techter, V.P., Allied Chemical & Dye Corp.
Albert B. Baker, partner, Bradley & Baker
A. B. Huyck, V.P., Brooklyn Union Gas Co.
T. J. Carpenter, V.P., De Bordeleben Coal Corp.
E. F. Schumacher, Dir. of Sales, Du Pont Co.
A. F. Reed, V.P., Lion Oil Co.
J. C. Leppart, Exec. V.P., Mathieson Chemical Corp.
G. W. McCullough, Exec. V.P., Phillips Chemical Co.
Richard F. Hopkins, President, San Jacinto Chemical Corp.
L. V. Steck, V.P., Shell Chemical Co.
John R. Riley, V.P., Spencer Chemical Co.
Walter Titlow, Mgr., coke and chemical sales, Allan Wood Steel Co.

Phthalic and Maleic Anhydrides

E. J. Boehm, Mgr. intermediates div. Nat. Aniline div., Allied Chemical & Dye Corp.
R. L. Cammann, V.P., Barrett Division, Allied Chemical & Dye Corp.
John F. Segelcke, product supervisor Industrial chemical division American Cyanamid Co.
T. C. Keeling, Jr., Sales Mgr. Koppers Co., Inc.
A. P. Kroeger, Asst. Gen. Mgr., sales Monsanto Chemical Co.
G. L. Parkhurst, chairman of board Oronite Chemical Co.
A. Evans, Jr., Mgr., coal chemical sales Pittsburgh Coke and Chemical Co.
Charles O'Connor, President Reichhold Chemicals, Inc.
N. E. Van Stone, V.P. Sherwin-Williams Co.

Carbon Bisulfide

H. B. Rasmussen, Tech. Dir. J. T. Baker Chemical Co.
Louis Preisman, Chief Eng. Barium Reduction Corp.
Louis P. Butenschoen, Mgr., solvent sales The Dow Chemical Co.
Arthur F. Smith, Mgr. Westvaco chemical div. Food Machinery & Chemical Corp.
T. A. Haschke, Sales Mgr. Stauffer Chemical Co.

Carbon Tetrachloride

W. H. McConnell, Dir. Sales Diamond Alkali Co.
Louis P. Butenschoen, Mgr. solvent sales Dow Chemical Co.
Arthur F. Smith, Div. Mgr. Westvaco chemical div. Food Machinery & Chemical Corp.
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Baskets, Dipping
Bearings
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Boilers
Boiler Covering and Insulation
Bolting Cloth
Bottling Machinery
Brick, Acid Proof
Brick, Insulating
Brick, Refractory
Briquetting and Tablet Making Machinery
Buckets, Elevator
Building Materials
Burners
Cabinets—Chemical, Filing and Laboratory
Calciners
Calorimeters
Cans
Carbon
Carboy Tilters
Cars, Tank
Castings
Caustic Pots
Cellulose
Cement
Centrifugals
Ceramics
Chemical Plant Equipment
Chemical Stoneware, Acid Proof
Chemicals, Industrial
Chemicals, Laboratory
Chemicals, Pharmaceutical
Chemists
Chlorinators
Clarifiers
Classifiers
Clutches
Coal Tar Oils
Coatings—Protective
Coils
Coke Oven Machinery
Collectors
Colloid Mills
Colorimeters
Colors, Dry
Comparators
Compressors
Concentrators
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Dryers, Centrifugal
Drying Machinery and Equipment
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Dust & Fume Collecting Systems
Dust and Spray Masks
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Engineers
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Exhausters
Explosives
Extraction Plants
Extractors
Feeders
Fillers
Filling Machines
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Filter Cloth, Metallic
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Filters
Fire Detection
Fire Extinguishers
Fire Proofing Compounds
Fittings
Flooring
Food Industries Equipment
Furnaces and Accessories
Gages
Gas Boosters
Gas Producers
Gas Purifiers
Gases
Gears
Glass—Optical
Glassware
Grating
Grinders
Heat Exchangers
Heaters and Heating Equipment
Heating Systems and Accessories
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Homogenizers
Hoods, Fume
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Instruments, Testing
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Pharmaceutical Machinery
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Plastics
Plasticizers
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Rotameters
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Rust Proofing
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Screens—other
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Separators
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Sifters
Silica
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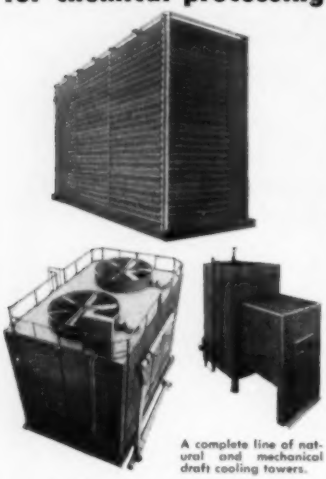

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PEOPLE

William T. Dixon has been appointed to the newly established post of manager of design in the engineering and construction department of Atlantic Refining Co., Philadelphia, Pa. Mr. Dixon joined Atlantic's research and development department in 1927. He became supervisor of chemical engineering design in 1937, and director of the engineering division in 1947. He received his B.S. from Princeton in 1924, and his M.S. from M.I.T. in 1926. Subsequently, he taught at M.I.T. Practice School, becoming assistant director of the Buffalo Station in 1926. He is Chairman of the A.I.Ch.E. Committee on Testing Techniques and Equipment Performance, and general chairman of the forthcoming A.I.Ch.E. Annual Meeting at Atlantic City.

William A. Hall has succeeded Mr. Dixon as director of the engineering division of the research and development department. Mr. Hall went to Atlantic in 1933, after obtaining his M.S. degree from M.I.T. He has served in the research and development department since then. He worked first in pilot unit operations, and then in process design, becoming assistant supervisor of chemical engineering design in 1940, and supervisor in 1946.

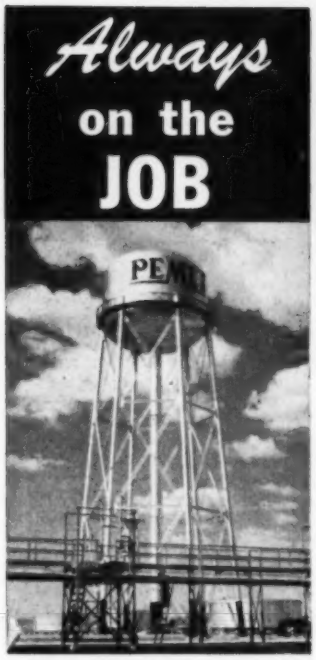
Albert H. Cooper has been appointed head of the research engineering department of the research and development division of the Davison Chemical Corp. He was formerly at Bucknell University where he was professor and head of the department of chemical engineering. Dr. Cooper received his bachelor's and master's degrees from the University of Tennessee and his doctor's degree in chemical and mechanical engineering from Michigan State College. He is a registered professional engineer in Virginia, Maryland and Pennsylvania.

Charles L. Campbell has been appointed chief engineer of the Centrifix Corp., Cleveland, Ohio, and will direct design development. For the past seven years he was chief engineer for the Diamond Alkali Co., Painesville, Ohio. Previously, Mr. Campbell was affiliated with the Barium Reduction Corp. and the West Virginia Pulp & Paper Co. He received his D.S. degree at the Sorbonne, Paris.

Robert W. Cretney has been appointed plant manager of the Thermatomic Carbon Co., Sterlington, La. He joined the company in 1923 as a chemical engineer, subsequently becoming superintendent of the Sterlington plant in 1942. Mr. Cretney, a graduate of the University of Wisconsin, was previously affiliated with the Western United Gas & Electric Co., Aurora and DuQuoin, Ill., and the Southern Illinois Gas Co., Murphysboro, Ill.

H. F. McConomy succeeds Mr. Hall as supervisor of chemical engineering design. He has been with Atlantic since 1934, and has been doing process design work since 1938. Prior to that, he was engaged in process development studies. He received a B.S. degree from Penn State in 1934. **J. C. Jubin** who has been promoted to assistant supervisor joined Atlantic after receiving a B.S. degree from Rensselaer in 1938. He has served in the process design section since then, except for a training period on the pilot units.

Robert L. Kelly has been named production supervisor in 53 Building, Vat Colors area of the Grasselli Works division, General Aniline & Film Corp., Linden, N. J. Mr. Kelly received a B.E. degree in chemical engineering from Yale University Engineering School in 1937. An engineer with the U. S. Rubber Co. for nine years, he joined General Aniline as an industrial engineer in March, 1950. He was a senior chemical engineer in the chemical engineering department until early in July of this year.



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Washington 6, D. C.	1123 Calvitz Bldg.

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H. L. Pelzer was recently appointed manager of the newly formed Sinclair Research Laboratories at Harvey, Ill,. where he has been assistant manager for the past five years. Mr. Pelzer, a graduate of the University of Illinois, has been with Sinclair since 1919. For 12 years he was with the research and development department of the East Chicago (Ind.) refinery. Following nine years as assistant superintendent of the Houston refinery, he returned to the research department.

E. C. Herthel was recently elected vice-president of the newly formed Sinclair Research Laboratories at Harvey, Ill. Mr. Herthel, a graduate of the University of Wisconsin, started with Sinclair in 1917 as supervisor for the East Chicago (Ind.) refinery. He was subsequently assistant to the manager of the Sinclair refineries, then manager of the research and development department. During the war years, he served on several advisory committees.

F. R. Fisher, a graduate of the Colorado School of Mines, was recently appointed secretary of the newly formed Sinclair Research Laboratories at Harvey, Ill. Mr. Fisher joined the company in 1940 and was active in pilot plant work for two years. Following three years' service with the Navy, he returned to the company as petroleum process designer and a year later was appointed administrative assistant to the manager, in which capacity he acquired extensive knowledge of the research organization.

Robert E. Wilson, chairman of Standard Oil Company (Indiana), presented the third Cadman Memorial Lecture June 21 at the Royal Institution, London, England. He addressed the Institute of Petroleum on "Competitive and Co-operative Research in the American Petroleum Industry." Second American to be so honored, Dr. Wilson received the Cadman Memorial Medal at the proceedings. The Cadman Medal is awarded by the Institute of Petroleum in memory of Lord Cadman, chairman of the Anglo-Iranian Oil Co. and the Iraq Petroleum Co.

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Frank M. Tiller, 1950 winner of the Junior Award of American Institute of Chemical Engineers (see "C.E.P." December, 1950, page 14) has been appointed director of the division of engineering for Lamar State College of Technology, Beaumont, Tex., which opens in September. Lamar Tech succeeding a 28-year-old junior college begins its initial year of upper division engineering training this fall. Dr. Tiller will supervise planning of curriculi for the five engineering programs. Currently he is associate professor of chemical engineering at Vanderbilt University. Dr. Tiller, who received his Ph.D. from the University of Cincinnati in chemical engineering in 1946 also will be professor and head of the department of chemical engineering at Lamar. He was a graduate assistant at Cincinnati from 1937-40 and an instructor from 1940-42. His professional experience includes work as a chemical engineer for the C. M. Hall Lamp Co., Detroit, and as a chemist for the Colgate-Palmolive-Peet Co. and Durkee Famous Foods. For a time he served as a civil engineer with the Flood Control division of the U. S. Army Corps of Engineers at Louisville.

James R. Kelly was recently appointed to the sales force of Monsanto Chemical Co.'s Merrimac division. Mr. Kelly has been assigned to industrial chemical sales. A graduate of the University of Delaware, where he received a bachelor's degree in chemical engineering in 1947, Mr. Kelly joined Monsanto's plastics division in Springfield, Mass., the same year. While in Springfield, he was employed as production supervisor in the Resinox phenolics plant. The new Merrimac division salesman is a naval veteran of World War II.

Robert E. Muller was recently elected a director of Luxene, Inc., New York, N. Y. He will serve as corporation secretary and will continue his former duties as director of research and production. He received his Doctor's degree in chemical engineering at the Polytechnic Institute of Brooklyn, Brooklyn, N. Y. After four years' affiliation with the Bakelite Corp. and a period with the Manhattan Project on atomic research, he joined Luxene in the dental plastics research department.

Paul F. Gans is now process engineer with C. F. Braun & Co., in Alhambra, Calif.

Howard K. Nason, assistant to the vice-president in charge of research, development and patents, has been appointed director of research of the organic chemicals division of Monsanto Chemical Co. Mr. Nason, a graduate of the University of Kansas, went to Monsanto in 1936, as a research chemist in the St. Louis plant of the company. From 1939-44, he was assistant director of research at Monsanto's plastics division in Springfield, Mass. He was transferred to the central research department at Dayton in 1944, as director of development and two years later became assistant director of the central research department. In 1948 he became director of central research and subsequently was transferred to St. Louis as assistant to Dr. Carroll A. Hochwalt, vice-president in charge of research, development and patents. Last year he was one of the men sent by Monsanto to the Advanced Management course at Harvard Graduate School of Business Administration.

W. M. Chow, formerly assistant professor in the chemical engineering department at Lafayette College, Easton, Pa., is now assistant professor in the chemical engineering department at Catholic University, Washington, D. C.

G. L. Bridger, professor of chemical and mining engineering at Iowa State College, has gone to New Zealand to consult with various industrial and agricultural people there on fertilizer manufacture. The survey, which will take about three months, is sponsored jointly by our State Department and the New Zealand Department of Agriculture.

George N. Havens has been appointed account executive with the Jayme Organization, an industrial advertising agency of Cleveland, Ohio. Formerly associated with the Brush Development Co., as sales engineer in the hypersonic division, Mr. Havens received his chemical engineering degree at Case Institute of Technology.

C. W. Johnston has been appointed head of the resin research section at the Baltimore research and development laboratories of U. S. Industrial Chemicals, Inc. He is a graduate of Columbia University and has been associated with U.S.I. since 1940, when he joined their New York City office. He was transferred to the Applied Research laboratories, June, 1951.

Walter K. O'Loughlin has been appointed manager of the development department of the research and development division of the Davison Chemical Corp., Baltimore, Md. He goes to Davison from the intelligence department of the Air Forces. Before that association he was with Commercial Solvents Corp. Mr. O'Loughlin received his bachelor's degree in chemical engineering from the Catholic University of America in 1933 and his master's degree in physical chemistry from the same university in 1935.

Appointment to these technical posts were announced recently.

Kenneth S. Watson, formerly assistant director of the Ohio River Valley Water Sanitation Commission, has been appointed co-ordinator of industrial waste treatment for the General Electric Co. Mr. Watson attended West Virginia University, where he received a Master's degree in chemical engineering in 1936. He was executive secretary-engineer of the West Virginia Water Commission before he entered the interstate pollution field. He was a member of the Interstate Commission on the Potomac River Basin, and chairman of its Technical Committee. During World War II, Mr. Watson served as a major in the U. S. Army Corps of Engineers. In the European Theater of Operation, he commanded an engineer combat battalion. Later he was Trade and Industry Officer for the City of Frankfurt, Germany.

Harry E. Roche has been assigned to special duties in the Koppers Co. chemical division's new Williams plant at Port Arthur, Tex. Mr. Roche, an alumnus of Cornell University, joined the company as an operating engineer in 1927. After an absence of seven years, he rejoined the company in 1941 and was successively superintendent of the research department, then of the butadiene division, and lastly production manager of the chemical division in Pittsburgh, Pa.

John W. Tierney returned to the Pure Oil Co.'s research laboratory at Crystal Lake, Ill., June 12, 1951. Dr. Tierney had been granted a year's leave of absence during which he received his Ph.D. from Northwestern on June 11. **Merk Hobson** began an extended stay with the Pure Oil Co.'s research laboratory at Crystal Lake June 12. Dr. Hobson is on the faculty staff of the University of Nebraska and will return there when classes resume next fall.

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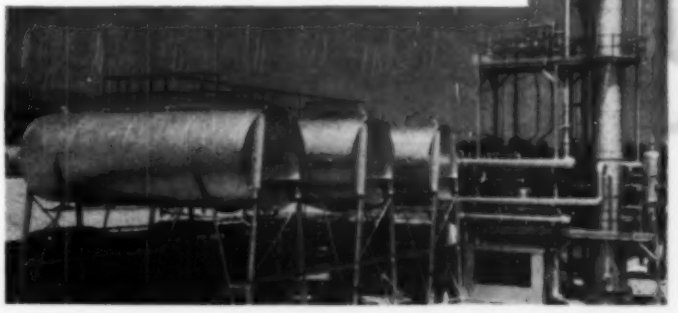

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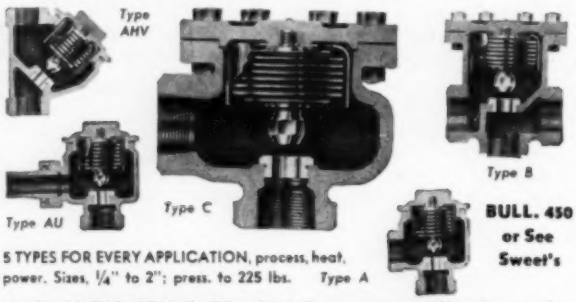

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Robert W. Schramm has been appointed manager of the market research section of the Spencer Chemical Co., Kansas City, Mo. He has been affiliated with that company since 1949 as a market analyst. Mr. Schramm, a graduate of the University of Notre Dame and the University of Indiana, was formerly associated with the Carbide and Carbon Chemical Corp., Whiting, Ind.

Michael F. S. Gigliotti has been appointed project construction engineer for the Monsanto Chemical Co.'s new plastics division plant at Addyston, Ohio. Since January, 1950, he has been sales representative for its New York office. He joined Monsanto as an assistant design engineer in 1942, after receiving his B.S. from Stevens Institute of Technology, Hoboken, N. J.

C. E. Rowe has joined the staff of Mathieson Hydrocarbon Chemical Corp. in the capacity of chief process engineer. He is now located at the company's Doe Run plant, under construction, near Brandenburg, Ky. For the past year he has been with Mathieson Chemical Corp., in the Research Engineering Group at Niagara Falls, N. Y.

Charles B. Rosen was promoted to project engineer for the process engineering section. After five years with the Shell Chemical Co. as a technologist, Mr. Rosen joined Monsanto in 1946, as a chemical engineer in the general development department. A year later he transferred with the process section to the General Engineering Department.

KITTNER WITH MONSANTO

Robert H. Kittner joined the general development department of Monsanto Chemical Co. in St. Louis on July 16. He had been production manager of the Industrial Rayon Corp. at Cleveland until recently.

He received a B.S. degree in chemical engineering from Case Institute of Technology (1928) and a chemical engineering degree from Columbia University (1929). Following graduation, he joined the American Hard Rubber Co., New York, to do sales development engineering work. In 1944, Mr. Kittner became manager of the plastics and chemicals division of the Glenn L. Martin Co., Baltimore, and in 1946 was named vice-president in charge of the chemicals division of that company. He joined Industrial Rayon Corp. in 1950.

Tod G. Dixon has been appointed executive assistant to the commissioner of the Department of Public Works in Nassau County, N. Y. The department engages in all phases of engineering as related to roads, bridges, sanitation and water, and Dr. Dixon will coordinate these services. He is a graduate of the Ohio State University, has had seven years' industrial experience and has been professor of chemical engineering and curriculum chairman at Pratt Institute from 1932 to 1951. He is a registered professional engineer and has been active in consultation work being associated with Litho Chemical and Supply Co. of Lynbrook, N. Y., and Messemer's Associates of New York. Since 1947 Dr. Dixon has been a trustee of the Inc. Village of Malverne, N. Y.

Robert M. Aude, who since 1947 has been general superintendent of the transportation and materials department, was recently appointed production superintendent of Monsanto Chemical Co.'s new plastics division plant in Addyston, Ohio. Mr. Aude received his B.S. degree from the University of Wisconsin in 1937 and joined Monsanto as a chemist in the plastics division. He was subsequently group leader of a process investigation group, supervisor of the continuous process department, then superintendent of the thermoplastic molding compound division.

E. Madison Jones has been appointed project leader of the process investigation group of the Monsanto Chemical Co., Texas City, Tex. He went to the plant in 1947, having joined Monsanto in 1946 as an analytical chemist in the Monsanto, Ill., plant. Mr. Jones received his M.S. degree from the University of Michigan and served in the U. S. Navy as a radar and counter-intelligence corps officer from 1943-1946.

Earl W. Flosdorf, director of research and development at the F. J. Stokes Machine Co., Philadelphia, Pa., was one of the speakers at a congress on "Freezing and Drying" held recently in London, England. Dr. Flosdorf, who is credited with a major part in the development of dried blood plasma, was the only representative of an American firm to be invited. He tentatively plans to visit Paris, France, and Basil, Switzerland, to discuss their equipment for blood banks.

R. B. Semple, president of the Wyandotte Chemicals Corp., was recently elected one of the directors of the Manufacturing Chemists' Association, New York, N. Y. **Robert L. Taylor,** editor of Chemical Industries, was appointed executive vice-president of the association.

Richard W. Kixmiller recently became assistant general manager of the chemical division of the Celanese Corporation of America, New York, N. Y. In this shift of personnel, **William Orr,** formerly with the Monsanto Chemical Co., Monsanto, Ill., became production superintendent at Bishop, Tex., and **H. K. Busch,** formerly staff chemical engineer, was promoted to assistant production superintendent at the Bishop plant.

Ralph R. Wenner was recently named assistant director in charge of engineering and process development for the Monsanto Chemical Co., St. Louis, Mo. Dr. Wenner attended Cooper Union Institute of Technology, Northwestern University and California Institute of Technology, where he received his Ph.D. degree. He joined the central research department of Monsanto in 1942 and was promoted to group leader in 1946.

Walter J. Armstrong, assistant manager of the international division and **Ralph E. Peck,** chemical engineer and drier specialist, of the Armour Research Foundation of Illinois Institute of Technology, recently began research work in Costa Rica. The project, sponsored by the Reconstruction Finance Corp., will concentrate on a full survey of Manila hemp, a critical item in the defense of the Western Hemisphere.

John D. Evans recently accepted a position as a chemical engineer in the engineering division of Commercial Solvents Corp., Terre Haute, Ind. He was formerly junior staff engineer for the Standard Oil Co., Hammond, Ind.

Manson Benedict has been appointed chief of operations analysis for the U. S. Atomic Energy Commission. Dr. Benedict, who received his Ph.D. in physical chemistry from Massachusetts Institute of Technology, will be on leave from his position as professor of nuclear engineering at M.I.T. In 1938-42 he was a research chemist with the M. W. Kellogg Co., in 1942-46 he was head of process development for the Kellex Corp, N. Y., and in 1946-51 he was director of process development for Hydrocarbon Research, Inc. In 1947 Dr. Benedict received the William H. Walker award of the American Institute of Chemical Engineers for a series of publications on distillation processes.

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CHEMICAL ENGINEER—Ph.D. 1945. Foreign citizen, security clearance. Experience process development, design, production fertilizers, detergents, glyceride oils, foods. Seek relocation to development and/or applied research in industry. Five foreign languages. Draft exempt. Location immaterial. Box 21-8.

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Necrology

E. E. WARE

E. E. Ware, special assistant to A. W. Steudel, president of the Sherwin-Williams Co. and superintendent of plant construction, died suddenly July 8. He held executive positions with the company since joining the organization in 1912. A lieutenant colonel in the ordnance branch of the U. S. Army during World War I, he was selected by the Sherwin-Williams Co. to direct the construction and operation of a shell-loading plant built at the request of the War Department at Carbondale, Ill. During 39 years with the Sherwin-Williams Co. his assignments included director of varnish research, superintendent of varnish production, and vice-president and technical director of the company. He was graduated from the University of Michigan as a chemical engineer. Ohio State University conferred upon him the honorary degree of D.Sc. in 1943 in recognition of his work in the paint and varnish field. Dr. Ware, who was 71 years old, was the author of many technical papers and was responsible for several industrial patents.

J. P. MAIDER

Joseph P. Maider died suddenly in his office at the Goodyear Tire & Rubber Co., Akron, Ohio. Following his graduation from Cornell University in 1911 with a Bachelor's degree in chemical engineering, Mr. Maider served for six years as chief chemist for the city of Spokane, Wash. He joined Goodyear in October, 1917, and held many positions in the research and development departments until he was made manager of chemical products in 1936. He was later appointed chemical production manager, a position he held until his death.

M. T. PAWEL

Morton T. Pawel, a 31-year-old development engineer for the Dorr Co., Stamford, Conn., died recently. He received his A.B. in chemistry from Cornell University in 1941 and spent the next year and a half with the Tennessee Valley Authority at Norris, Tenn., and Wilson Dam, Ala. After a year and a half with the U. S. Bureau of Mines, he spent the next three years with the U. S. Army in Iowa, Oak Ridge, and Washington, D. C. He joined the Dorr Co. in 1946 as chemical engineer and was appointed to his most recent position in September, 1950.

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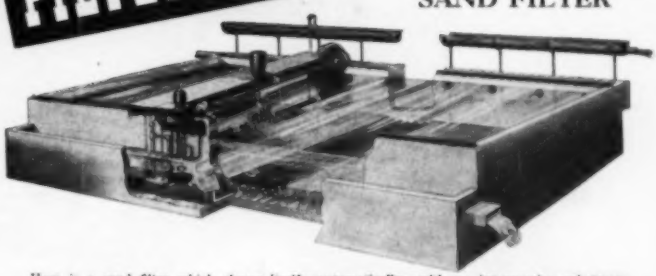

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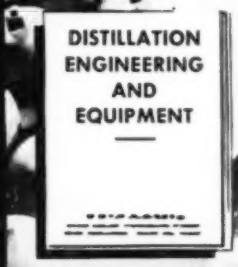

Write for copy of technical bulletin "Distillation Engineering and Equipment"

• • • the separation of hydrocarbons or other organic chemicals, should be designed for efficiency in terms of overall operating costs and amortization of capital investment. Tray efficiency, cleaning facility and resistance to corrosion are the prinicipal factors to be considered. For practical purposes, tray efficiency or tray spacing may be reduced to keep tower cost at a minimum. A balance of utility costs against chemical recovery may indicate the desirability of sacrificing some of the recoverable material, with a corresponding reduction in the capital outlay for columns and associated calandrias, condensers and heat exchangers. Particularly when potential changes in process or product specifications are foreseen, distillation columns with sectional shells and removable trays of light alloy construction offer special opportunities for economy because of the ease of transfer from tower to tower as well as cleanability and resistance to corrosion.

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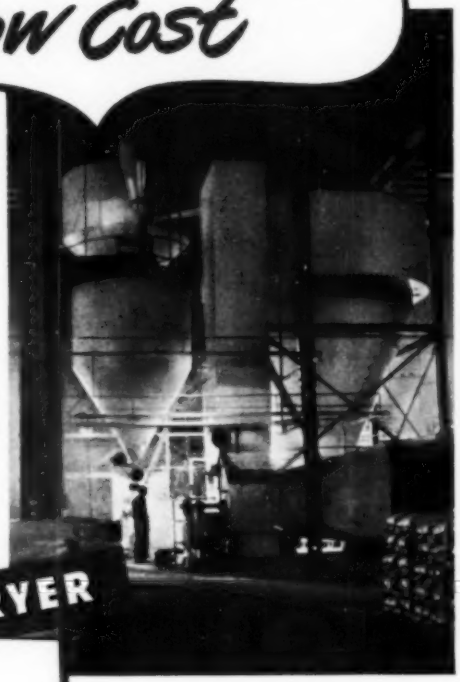

Here is high-capacity spray-drying equipment that is especially suitable for handling heavy chemicals. It is direct fired, uses either oil or gas as fuel, and gives amazingly low-cost operation.

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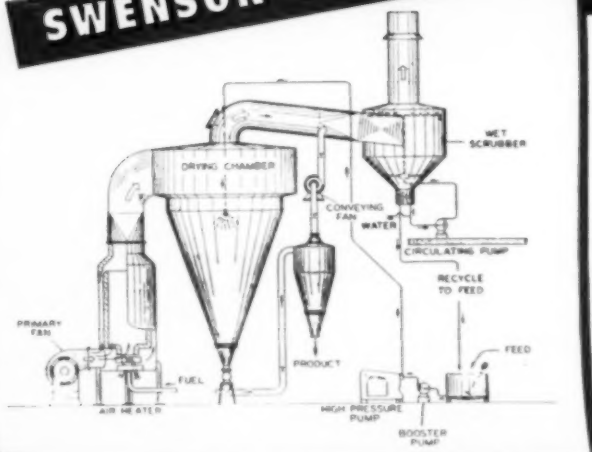
SWENSON SPRAY DRYER



Flow sheet shows typical spray-dryer installation for handling heavy chemicals.

Direct-fired spray drying may be used for such materials as:

Silica gel

Kaolin clay

Manganese sulfate

Calcium carbonate

Chrome sulfate

Sodium phosphate

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